

# Energy Efficient Polymers for Seawater Heat Exchangers

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## 1. Introduction

The present study explores the thermofluid characteristics of a seawater-methane heat exchanger that could be used in the liquefaction of natural gas on offshore platforms. The compression process generates large amounts of heat, usually dissipated via plate heat exchangers using seawater as a convenient cooling fluid. Such an application mandates the use of a corrosion resistant material. Metals such as titanium, expensive in terms of both energy and currency, are a common choice. The “total coefficient of performance,” or  $COP_T$  [1], which incorporates the energy required to manufacture a heat exchanger along with the pumping power expended over the lifetime of the heat exchanger, is used to compare conventional metallic materials to thermally conductive polymers.

The thermofluid characteristics of heat exchangers built of high thermal conductivity polymers are analyzed, for conditions typically seen by ADGAS. It assumes a 1 year service life for a typical plate heat exchanger, though heat exchangers operating in such corrosive environments may have far shorter service lives. In this study the hot natural gas is represented by 90°C methane and 35°C seawater is used as the coolant. Gas is flowing through the heat exchanger at 10 m/s, and water at 0.5 m/s. Analytical models were used to calculate the heat transfer rates and the required pumping power, as well as additional metrics, over a range of fin spacings, wall thicknesses, and thermal conductivities.

## 2. Key Features

The plate heat exchanger studied here is shown in Figure 1, with process temperatures of 90°C methane and 35°C seawater. This heat exchanger was analyzed based on not only the geometry, but the invested energy content of the material. Thermally-enhanced polymers provide an interesting thermal optimization opportunity. A typical thermally-enhanced polymer is a composite material of a base polymer, such as nylon or polypropylene, and carbon fiber fillers. These fillers have the potential to increase the thermal conductivity by one to two orders of magnitude, but with this follows an increase in the invested energy of the material. The lifecycle energy content of a thermally enhanced polymer is plotted in Figure 2 as a function of thermal conductivity. This energy content can be seen to increase dramatically, from 75 MJ/kg to 240 MJ/kg as the thermal conductivity is increased from 1 W/mK to 25 W/mk. Figure 3 shows the fraction of total lifetime energy consumption that is invested before the heat exchanger is installed. Aluminum, Titanium, an unfilled polymer, a low-k polymer (5 W/mK), and a high-k polymer (20 W/mK) are compared. It can be seen that, for the short service life typical of seawater heat exchangers, the energy invested in manufacturing dominates. For a titanium heat exchanger, less than 5% of energy is used in operation.

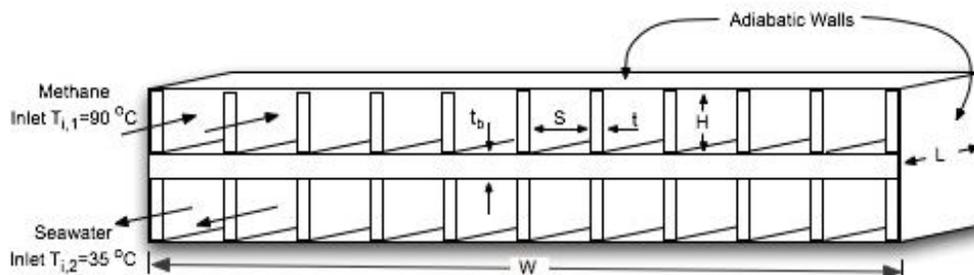


Figure 1. Doubly finned parallel counterflow heat exchanger.

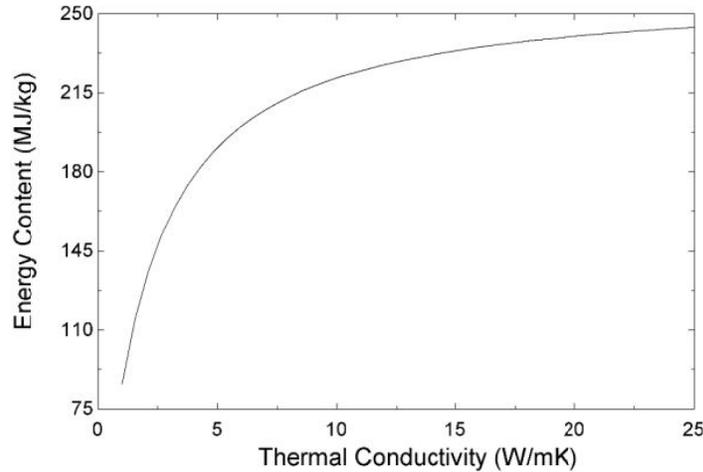


Figure 2. Composite Polymer Energy Content as a function of thermal conductivity ( $k_f=500\text{W/mK}$ ,  $E_f=286\text{ MJ/kg}$ ,  $k_p=0.25\text{W/mK}$ ,  $E_p=24\text{ MJ/kg}$ ,  $\Phi_m = 0.82$ ).

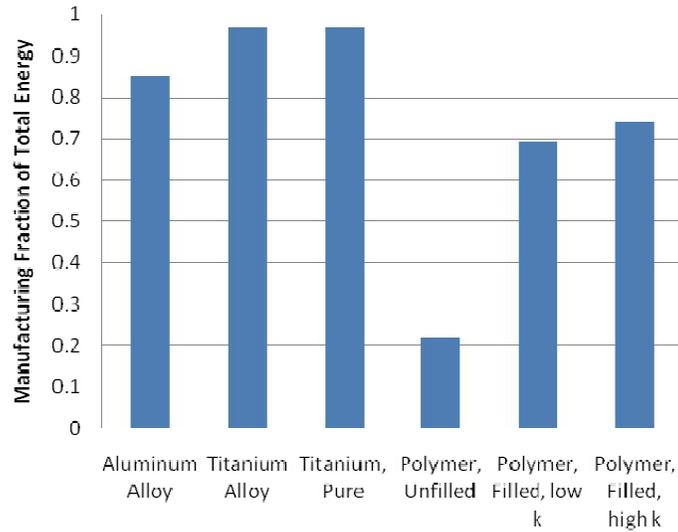


Figure 3. Energy invested in heat exchanger as a function heat exchanger material ( $t_f=1\text{mm}$ ,  $t_b = 1\text{ mm}$ ,  $H = 10\text{ mm}$ ,  $W = L = 1\text{ m}$ ,  $S = 5\text{ mm}$ ,  $u_1 = 10\text{ m/s}$ ,  $u_2 = 0.5\text{ m/s}$ , 1 year service life).

Figure 4 compares the thermal performance of several potential heat exchanger materials. For the low heat transfer coefficients typical of a gas-liquid heat exchanger, a high-k polymer, as well as titanium, can be shown to give 93% of the thermal performance of aluminum. Even the low-k polymer, at 5 W/mK, gives 81% of the performance of aluminum.

The results of the total coefficient of performance metric are shown in Figure 5, which the fin dimensions for each material set to the best-operating dimensions. Aluminum, with a large thermal conductivity, will have tall, thin fins, while the unfilled polymer will have shorter, thicker fins. While the unfilled polymer results may not be relevant due to its poor thermal performance, the thermally enhanced polymer can be seen to perform 48% better than an optimized aluminum heat exchanger, and nearly 7 times better than a titanium heat exchanger.

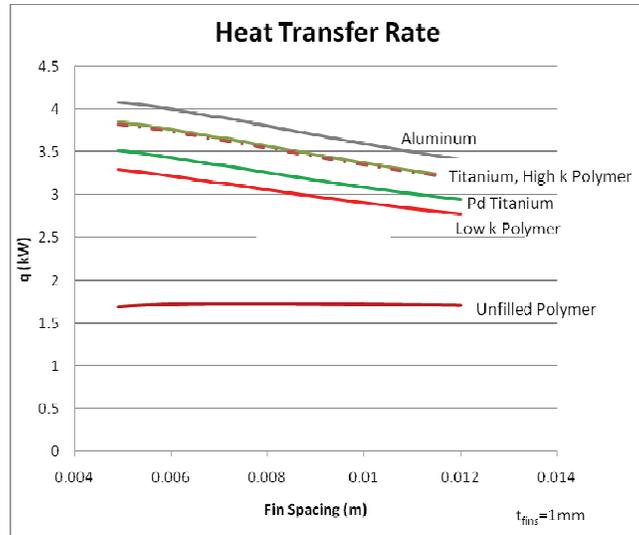


Figure 4. Heat exchanger performance as a function of fin spacing and heat exchanger material ( $t_b = 1$  mm,  $H = 10$  mm,  $W = L = 1$  m,  $u_g = 10$  m/s,  $u_w = 0.5$  m/s).

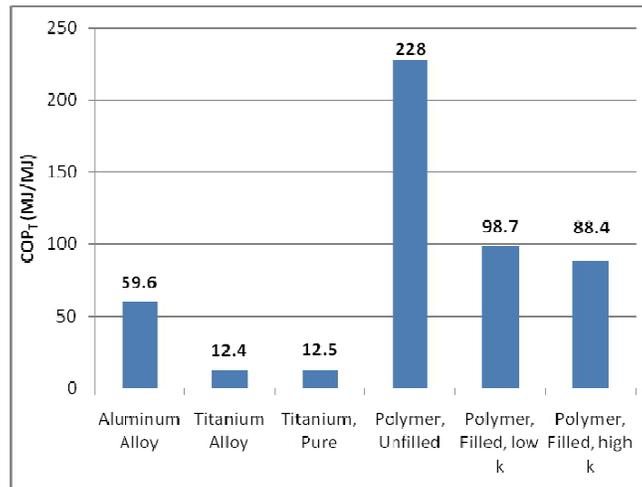


Figure 5. Best-operating condition COP<sub>T</sub> for doubly finned counterflow heat exchanger ( $t_b = 1$  mm, optimum height, fin spacing & fin thickness,  $W = L = 1$  m,  $u_1 = 10$  m/s,  $u_2 = 0.5$  m/s).

### 3. Conclusions

Parametric analyses of predicted heat exchanger COP<sub>T</sub>'s, which incorporates energy efficiency, reveal that exchangers fabricated of low energy, low thermal conductivity polymers can perform better than those fabricated from conventional materials (e.g., titanium, 22 W/mK) over their full lifecycle. The low thermal conductivity (5 W/mK) filled polymer heat exchanger analyzed in this study performed 48% better than an optimized aluminum heat exchanger, and 7 times better than a high energy, high cost titanium heat exchanger. This study shows that thermally enhanced polymers are a viable heat exchanger candidate material, due to their low fabrication energy and overall lifetime energy use. It was found that the energy invested in manufacturing of such heat exchangers could dwarf the lifetime energy expended in pumping, especially for the short service lives typical of heat exchangers in corrosive environments.

### 4. References and Bibliography

1. Bar-Cohen, A., R. Bahadur, and M. Iyengar, *Least-energy optimization of air-cooled heat sinks for sustainability-theory, geometry and material selection*. Energy, 2006. 31(5): p. 579-619.

**Author Biographies**

**Mr. Patrick Luckow** received his B.S. in mechanical engineering from Northwestern University, in Evanston, Illinois, U.S.A. He is currently pursuing his M.S. degree at the University of Maryland, College Park in mechanical engineering. Here he is performing research on the development of polymer heat exchangers for seawater applications, while also supporting activities at the University of Maryland Energy Research Center (UMERC). His interests include design for sustainability, least-material optimization, energy efficiency and renewable energy.

**Dr. Avram Bar Cohen** is Distinguished University Professor and Chair of Mechanical Engineering at the University of Maryland, where he continues his research in the thermal management of Micro/Nano systems. His interests include thermal design, ebullient heat transfer, and thermal phenomena in microelectronic, photonic, and biological systems, as well as technology forecasting and management of technology. Bar-Cohen was a founding member and currently serves on the Advisory Board of ASME's Nanotechnology Institute and represents ASME on the Assembly for International Heat Transfer Conferences (2002-2006). Prior to accepting his current position, he served as the Director of the Center for the Development of Technological Leadership and held the Sweatt Chair at the University of Minnesota, where he earlier served as Professor of Mechanical Engineering and Director of the Thermodynamics and Heat Transfer Division.

**Dr. Peter Rodgers**, Ph.D., is Associate Professor of Mechanical Engineering at The Petroleum Institute, U.A.E. He has extensive experience in thermofluid modeling and experimental characterization. His current research activities are focused on waste heat utilization in the oil and gas industry; the development of polymeric heat exchangers for sea water cooling applications; computational fluid dynamics; electronics reliability; and engineering education. He is presently a member of several international conference program committees, and serves as program co-chair for both EuroSimE 2009 and Energy 2030. He has authored or co-authored over 60 journal and conference publications.