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Energy recovery from regassification of cryogenic liquids using isobaric expansion technology

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The regasification of cryogenic liquids, such as liquefied natural gas (LNG), liquid hydrogen (LH_2), and industrial gases like nitrogen and oxygen, offers an unique opportunity for energy recovery during their transition from liquid to gas and subsequent gas heating to ambient temperature. Liquefaction of gases for their transport and storage occurs at extremely low temperatures and requires significant energy expenditure. However, most current regasification processes are largely passive and fail to recover any of the energy invested during liquefaction. This study presents a novel method to capture part of the lost energy by integrating Isobaric Expansion Engines (IEEs) into the regasification process

IEEs perform a simple and low-cost process. A gaseous working fluid at a low pressure is condensed when cooled by a cryogenic liquid. It is then compressed and heated by any available ambient heat, turns back into gas and produces useful work during isobaric expansion.

The system exploits the high temperature difference between the cryogenic liquid and the environment by utilizing an inert working fluid undergoing isobaric expansion, enabling energy recovery that directly offsets the energy-intensive nature of the liquefaction process. A thermodynamic evaluation of noble and inert gases; neon, argon, krypton, xenon, and nitrogen was conducted to assess their suitability as working fluids in this application. These gases exhibit properties together with acceptable safety profiles that make them ideal for energy extraction in IEEs. Heat regeneration was investigated that can increase recovery efficiency; the effect increases exponentially at larger temperature differences.

The study involved the development of a performance model comparing energy recovery efficiencies for each working fluid. The analysis demonstrated that the use of inert gases allows for the recovery of substantial portions of the original liquefaction energy when matched appropriately with the temperature profile of the regasification process. Notably, gases like argon and nitrogen offer an excellent balance between thermal performance and ease of handling. Neon, while thermodynamically attractive at ultra-low temperatures, poses practical limitations due to its narrow liquid range under moderate pressures. Xenon and krypton show a promise in higher-temperature stages of the regasification curve.

To maximize the efficiency of cold utilization, several methods can be employed, such as using an IE cycle with mixed working fluids instead of single-component ones, as mixtures can significantly enhance efficiency through improved heat regeneration. Another effective approach is the use of a cascade of several IE cycles, where multiple IEEs are arranged in series, each operating within a specific temperature range and utilizing an optimized working fluid.

The application of this technology aboard hydrogen-powered marine vessels was also explored. In such settings, recovered energy from LH_2 regasification can be reintegrated into the vessel's power management system, reducing auxiliary fuel consumption or enabling smaller hydrogen storage tanks. This is particularly important in marine transport, where space and energy density are critical.

Integrating IEEs into the cryogenic liquid handling process provides a meaningful step toward improving round-trip efficiency across the hydrogen and LNG value chains. While conventional hydrogen liquefaction processes consume around 10 –15 kWh/kg-H_2, the ability to recover energy during regasification can significantly reduce net energy costs. This aligns with global energy goals to increase the viability and sustainability of hydrogen and LNG as clean energy carriers. Furthermore, using inert, non-reactive working fluids mitigate safety risks.

The findings support the use of inert gases in both single and cascade IEE configurations, offering a technically feasible and scalable solution for energy recovery. As industries seek to decarbonize and enhance energy efficiency, the integration of IEEs presents a forward-looking strategy to reduce energy waste and improve the sustainability of cryogenic systems.

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