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LNG WASTE COLD RECOVERY FOR FUTURE SUSTAINABLE COOLING

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ABSTRACT

The world currently has 117 Liquefied Natural Gas (LNG) regasification facilities, collectively processing 14,400 m^3/s of natural gas. Most of the facilities use processes which waste the cold energy, the most common of which discharges it at sea. Globally, up to 6.1 GW of cold energy can be recovered from LNG regasification terminals, delivering sustainable cooling chain to industries were low-grade waste heat is generated and cooling is required. This paper has proposed a direct heat exchange system, in which cold energy from LNG regasification can be fully recovered and utilised through the use of a brazed plate heat exchanger. Feasibility of implementing the system has been carefully examined through computational fluid dynamics modelling and experimental validation. The results suggested an optimal LNG to water/ethylene-glycol solution mass flow ratio of 1:6 most appropriate with the heat exchanger. This can potentially recover around 37 MJ of cold energy from an average sized LNG regasification terminal.

Keywords: Liquefied natural gas (LNG); Cold energy recovery;

1. INTRODUCTION

LNG (liquefied natural gas) technology is an extremely large industry which is showing continual growth. By 2030 natural gas is forecast to rise to 26% of world energy usage [1] with a quarter of all natural gas traded internationally being via LNG [2]. In 2019 the global LNG demand is around 44 billion cubic feet per day (14,400 meters cubed per second). Theoretically, there is potential to harness up to around 6.1 GW of cold energy globally. This figure is expected to rise to around 13.3 GW by 2035 [3]. Global regasification methods very rarely attempt to harness any of the cold energy potentials with less than a hundredth being utilised [1]. Currently, 70% of regasification facilities discharge cold energy into the sea using a method named open rack vaporisation [4]. While not only is this hazardous to marine environments, this is a considerable amount of energy potential that is wasted, globally around 4.3 GW. A further 25% is regasified by burning natural gas to produce heat. Not only does this waste over 1.9 GW of potential cold energy, but 1.7% of the final natural gas product is wasted in this process (equating to around 40 kilograms per second globally). While efforts to harness some of this potential have already been made, for example creating electricity or integrating with industrial processes, these projects are relatively small scale, and no research has been performed on directly harnessing cold energy for cooling applications.

LNG terminals are designed to offload and regasify LNG as quickly as possible, meeting customer demand and achieving a fast turnaround for tanker ships to continue with next job. To capture cold energy for useful purposes as well as accomplishing desired regasification rates, heat exchangers are considered most relevant, and in particular, a brazed-plate heat exchanger (BPHE) has been proposed to facilitate direct heat exchange between LNG stream and an appropriate waste heat source or cold sink. Potential uses of the otherwise wasted cold energy may be district cooling network, data centres or integration with novel hydrate-based desalination [5].

Owing to the corrugation design of plate heat exchanger, higher contact surface increases the heat transfer coefficient and boosts the capability for heat transfer. In the BPHE, the corrugation and the interruptions given by the brazing points lead to highly

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turbulent flows favouring the heat transfer process. For a typical BPHE, operating temperature range goes from -195 to +220 °C while pressure can go up to 40-65 bar [6]. Moreover, since it is composed of stainless steel and does not have the sealing made of rubber gaskets, this type of heat exchanger can be used with aggressive and corrosive fluids.

In this work, a systematic approach is taken to investigate the feasibility of using BPHE to harness waste cold energy. By developing a Computational Fluid Dynamics (CFD) model and carrying out experimental validation, potential issues such as freezing within the heat exchanger channels were investigated.

2. METHODOLOGY

2.1 CFD modelling of direct heat exchanger using a brazed-plate heat exchanger

Concerns over the feasibility of using BPHE when using cryogenic fluid and heat exchange fluids due to freezing, it is necessary to perform a comprehensive analysis of the problem before applying the experimental campaign can be carried out. For this study, a downscaled and simplified CFD model was developed using COMSOL Multiphysics® in addition to the identification of an appropriate working fluid.

2.1.1 Working fluid selection

Several working fluids were considered for use in this system. The primary considerations when selecting a working fluid were:

- A fluid with sufficiently large heat capacity
- A fluid with a low freezing point
- A fluid which will not damage or be detrimental to equipment

For those reasons, several working fluids were carefully examined, such as liquid ammonia, supercritical carbon dioxide, sodium chloride solution and water/ethylene-glycol solution. Liquid ammonia is a common heat transfer fluid. However, the corrosiveness, the ability to easily form a toxic gas, and requirement of elevated pressures make it challenging to use for this application. Supercritical CO_2 is used for many cases as heat transfer material, but it requires at least 7.2 bar of pressure to keep supercritical and the associated extra equipment involved and impact on the choice of material made it less competitive. Sodium chloride solution initially appeared to have excellent properties for a heat exchange fluid, but many have reported the precipitation of salt crystals when travelling through heat exchangers [7], causing an increase in fouling and degradation in heat exchanger performance over time. Water/ethylene-glycol solution is sufficient in lowering the freezing point of water while maintaining its viscosity and heat capacity. While other heat exchange fluids may be better at the purpose of lowering freezing point and giving less of a compromise on viscosity and heat capacity, the ethylene-glycol solution has the benefits of non-toxicity and no risks of particle formation. Having examined how freezing point, viscosity and heat capacity are affected by concentration, an optimal concentration of 30% has been selected, enabling the freezing point for the solution of -13.7°C.

2.1.2 Modelling setup

A 3D image of the heat exchanger is shown in Fig 1, highlighting the pattern changes due to the chevron arrangement of the plate corrugations. Due to these corrugations and to the brazing point used to join the plates in different contact points, going in a direction perpendicular to the one shown in the images, leads to a wavy form of the pattern.

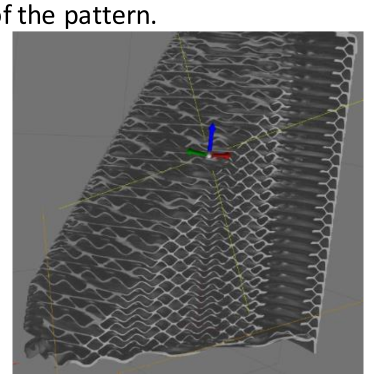

Fig 1. 3D image of BPHE obtained from x-ray scanner

Based on the 3D image of the BPHE and post-processing, it is possible to translate it into 2D geometry for the CFD modelling with COMSOL Multiphysics®. In this particular case, the heat exchanger and LNG regasification process have been downscaled to allow feasibility study and proof of concept to be undertaken. The CFD model analysed a ten plates BPH with lengths of 329mm, the height of 2.9mm and plate thickness of 0.385mm. Water/ethylene-glycol and LNG are allocated in an alternating arrangement, with six channels of Water/ethylene-glycol and five channels of LNG.

Parameters such as temperature, mass flow, pressure are implemented via boundary conditions. Table 1 reports these parameters. LNG temperature is assumed at -160 °C, while water/ethylene-glycol solution at 40°C, which the assumption is based on the temperature of low-grade waste heat source, from a nearby chemical plant, district cooling network or a data centre.

Table 1. Modelling input parameters adopted

Parameter	Values
LNG inlet mass flow [kg/min]	1
LNG inlet temperature [°C]	-160
Water/ethylene-glycol inlet mass flow [kg/min]	1.31 to 21
Water/ethylene-glycol inlet temperature [°C]	40

2.2 Experimental testing and heat exchanger validation

To validate the CFD model, an experimental campaign is carried out using identical input parameters as used in the computation.

2.2.1 Experimental setup

The experimental rig used is illustrated in Fig 2Fig 2(a). A pressurised tank and a hydraulic pump are used for storage and getting the LNG to the desired pressure before allowing it to flow through the BPHE. The heat exchanger and its inlet/outlet connection configuration are depicted in Fig 2Fig 2(b), with green plastic tubes and stainless steel pipes for transporting water-ethylene-glycol solution and LNG respectively. Thermocouples were attached to each of the inlet and outlet points, taking sample readings to a data logger.

(a) (b)

Fig 2. (a) Experimental setup; (b) BPHE setup

3. RESULTS AND DISCUSSION

In this study, both experimentation and computational modelling took place.

Table 2 summarises the average outlet temperature of each channel for each water/ethylene-glycol solution mass flow and the average temperature for both media.

The CFD based analysis has presented the evaluation of the most suitable water/ethylene-glycol solution flow range in which the fluid freezing problem was reduced to a minimum. Thus, using a parametric sweep the temperature distribution along the channels was evaluated for each water/ethylene-glycol solution mass flow. Fig 3 shows how the varying temperatures within the system are represented by varying colours. The five channels which enter as blue on the left-hand side, are the channels containing LNG, whereas the channels

Table 2. Summary of average channel outlet temperature for different water mass flow rate

	Temperature [°C]					
	1.31 kg/min	2.63 kg/min	5.25 kg/min	7.5 kg/min	10.5 kg/min	21 kg/min
Channel 1 (Water/ethylene-glycol)	-14.72	15.18	26.79	30.26	32.88	36.45
Channel 2 (NG)	-22.86	3.16	19.19	24.90	28.98	34.42
Channel 3 (Water/ethylene-glycol)	-29.91	-6.54	13.24	20.74	25.97	32.86
Channel 4 (NG)	-34.53	-10.55	11.38	19.89	25.64	32.74
Channel 5 (Water/ethylene-glycol)	-37.43	-13.00	10.14	19.33	25.43	32.67
Channel 6 (NG)	-37.94	-13.24	10.18	19.43	25.45	32.68
Channel 7 (Water/ethylene-glycol)	-37.83	-13.15	10.28	19.53	25.47	32.70
Channel 8 (NG)	-35.19	-10.80	11.50	20.03	25.66	32.76
Channel 9 (Water/ethylene-glycol)	-32.34	-8.29	12.68	20.53	25.87	32.82
Channel 10 (NG)	-25.74	1.15	19.06	24.90	29.05	34.54
Channel 11 (Water/ethylene-glycol)	-20.94	8.28	23.91	28.24	31.49	35.86
Average Water/ethylene-glycol channel	-28.86	-2.92	16.17	23.11	27.85	33.89
Average NG channels	-31.25	-6.06	14.26	21.83	26.96	33.43

which enter as red on the left-hand side contain water/ethylene-glycol solution. As each flows from left to right, heat is given up from the water/ethylene-glycol stream to the LNG stream until they exit at similar temperatures.

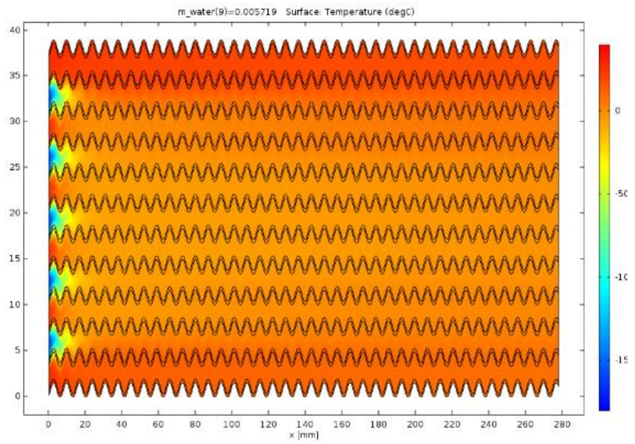

Fig 3. Temperature distribution, water/glycol solution flow at 7.5 kg/min

Due to the risk of water-glycol solution freezing within the heat exchanger, the minimum mass flow rate used was 5.17 kg/min, and only four sets of tests were eventually undertaken. Fig 4 plotted and demonstrated the comparison of modelling and experimental results. The prediction and experimental data were insufficient alignments with each other up until a certain point, where at minimum allowable water-glycol solution mass flow of 5.17 kg/min, a sudden drop in temperature of LNG was observed, indicating the formation of ice between plates, significantly reduces the heat transfer ability of the water-glycol solution.

The downscaled CFD modelling and experimental results clearly show the potential for a BPHE to be applied for the direct heat exchange and gasification of LNG, coupled with a low-grade waste heat stream from such as data centre, food manufacturing, district cooling networks and other industrial sectors. Although detailed studies of BPHE and impact of an increase in sizes and plates are needed before a full industrial scale implementation is taken place.

4. CONCLUSIONS

Research has been performed to investigate the potential energy efficiency improvement through recovering waste cold energy from liquefied natural gas regasification process. Computational fluid dynamics analysis and experimental work has been undertaken.

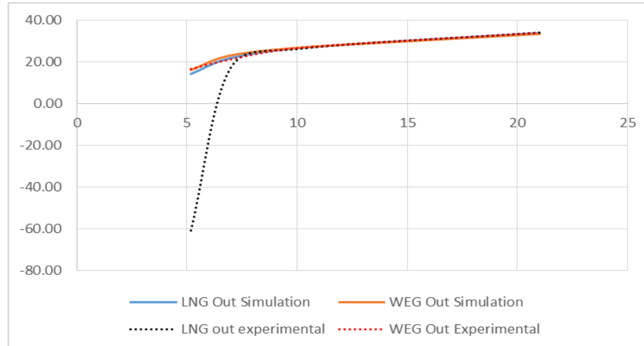

Fig 4. Comparison of modelling and experimental results

and the results support the integration of LNG regasification with other industrial processes that produce low-grade waste heat and demands cooling, for example, data centres and district cooling networks. The results suggested an optimal LNG to water/ethylene-glycol solution mass flow ratio of 1:6 most appropriate with the heat exchanger. This can potentially recover around 37 MJ of cold energy from an average sized LNG regasification terminal.

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