Techno-Economic Assessment of LNG Re-gasification Alternatives in Pakistan

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Dedication

This thesis along with my entire educational wouldn’t have been possible without commitments of my parents whom I fully envy and dedicate this thesis to. Also, the sheer persistence of my teachers has been phenomenal to motivate me and impart the knowledge.

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All praises to Allah Almighty, who bestowed in men the wisdom, intellect and inquisitiveness fostering endeavors. For this Thesis in particular, I am grateful to **Dr. Muhammad Taqi Mehran** for the involvement. It wouldn’t have been possible without him. Moreover, my teachers have been extremely cooperative and entertained any problem encountered during the passage of this research.

Abstract

With the passage of time, natural gas has emerged as a clean and efficient alternative to traditional fuels like coal, diesel and furnace oil. This demand requirement has fueled Liquefied Natural Gas (LNG), an energy intensive product and converted to cryogenic liquid at a temperature of -162.3˚C, reducing the volume by 600 times. With domestic resource depletion and rising demand of natural gas has pushed Pakistan to import LNG. Pakistan being a new entrant to LNG market relies on costly offshore FSRU (Floating Storage and Regasification unit), without any study underlining the other LNG regasification alternative available and the likely environmental variables impacting the regasification processes. In order so, this study is focused on techno-economic evaluation R-LNG processes. For this study, the various utilities like the seawater, ambient air, waste heat integration, hybrid modules and various others. Moreover, various structural configurations like Open Rack Vaporizer (ORV), Intermediate Fluid Vaporizer (IFV) variant and submersible combustion vaporizer (SCV) are also a point of focus. Moreover, the modelling and simulations for the respective regasification Techniques employed PRSV equation of state complimented by physical heat transfer laws and equations. In all this, environmental parameter underlined the choice of onshore integrated system utilizing. Moreover, the climatic considerations and temperature impacted the process efficiency, resultantly leading to failures and environmental costs. To this, NG as a fuel demonstrated high operational efficiency unaffected by the environmental parameters. While the integrated systems along with novel IFV are phenomenal in efficiencies and little productivity losses. Lastly, the operational and capital cost underlined that IFV system along with higher efficiencies is the best alternative.

Keywords

LNG, IFV, FSRU, Cold energy storage, Comparative utilities, SCV, ORV

Abbreviations

LNG-Liquified Natural Gas
NG-Natural Gas
FSRU-Floating Storage and Regasification unit
FPSO-Floating Production Storage and Offloading
IFV-Intermediate Fluid Vaporizer
IFVGA- Intermediate Fluid Vaporizer Glycol-Air
IFVG- Intermediate Fluid Vaporizer Glycol
IFVP- Intermediate Fluid Vaporizer Propane
CLIH-Closed Loop Indirect Heating
DH-Direct Heating
AAU-Ambient Air Unit
ORV-Open Rack Vaporizer
SCV-Submerged Combustion Vaporizer
HPS-High Pressure Steam
MPS-Medium Pressure steam
LPS- Low Pressure System
WHR-Waste Heat Recovery
IANW-Integrated Air and Water
PRSV- Peng-Robinson-Stryjek-Vera Equation of State
LHV-Low Heating Value
MMBTU-Million British Thermal Unit
RGTSU- Regasification Terminal Sungai Udang Melaka
RGTPJ-Regasification Terminal Pengerang Johor
BCM- Billion Cubic Meters
EPA- Environmental Protection Agency
BOG-Boil-of Gas

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Chapter no. 1

1. Introduction

1.1 Background of Study

The current era is witnessing a surge in temperature profile worldwide accompanied by additional catastrophes. This is attributed to the global warming due to unsustainable practices causing increase in concentration of greenhouse gases in atmosphere. This energetic model is manifestation of high carbon intensive fuels. There is increased sense of awareness and calls for action to act and avert this damage [1].

With the passage of time natural gas has emerged as a clean and efficient alternative to traditional fuels like coal, diesel and furnace oil [2]. Moreover, it can act as a bridge to cleaner renewable fuels. Natural gas has a lower carbon footprint and less pollutant emissions comparatively [1].Besides, natural gas currently share about 22% of world fuel needs [3] along with an increasing demand and market forecasted to increase by 1.7-2.4% per year with current trend and depending upon global policy directives [4][5].Thus , LNG will be the second major source of fuel by the year 2030 [6].

With little domestic production worldwide, the focus is to import from resources rich countries. In order so, either it’s the gaseous state with extreme volume through gas pipelines or the liquefied state in the form of cryogenic liquid moved through specialized tankers .Also, the studies have shown for a smaller distance, pipelines are an efficient means , while for longer and rugged terrain the Liquefied Natural gas is better alternative [7].Moreover , one third of NG transport occurs in the form of LNG [8].Hence providing the importing countries a free deal of flexibility and freedom from any political setbacks [9].

Liquefied Natural Gas is a product of energy intensive process, this conversion to cryogenic liquid at a temperature of -162.3˚C reduces the volume by 600 times [9] And the energy demand is equivalent to 10% of supplied NG [10].The high energy spent on liquefaction is not entirely wasted, some of it can be recovered through the cold energy utilization and poly-generation processes [11].Still, the capacity and recovery of cold energy is under developed due to impeding technological offsets. Thus, the overall energy intensity is cumulative sum of the gasification, transportation and regasification making it an expensive commodity [12].

They are numerous models and process for the regasification of the LNG with different structural and utility composures. Starting from air, water, types of steam, waste energy, or the direct heating by burning of natural gas. The conditions of environment greatly influence and impact the selection criteria for any regasification plant anywhere in world. Also, economy of a process and capacity parameter are vital to these considerations [13].Since, this physical process selection will be upon the optimization of characteristics and minimization of cost. Thus, a comparative analysis will help establish the feasible and cost-efficient process.

Firstly, there is a common use of seawater as a heating fluid for the gasification of LNG, while the sea temperature varies around the year. Also, the high transfer coefficient, specific heat and availability make it an ideal exchange media. Moreover, Air like water has variable property profile year around. With low heat properties, and large flow availability [14].

FSRU ship is an onshore regasification plant with a capacity to relocate and simultaneously store LNG onboard. It come with various sizes and capacity ranging from 100-600 MMSCFD .Besides, there are multiple different arrangement in it utilizing water as utility like the Intermediate Fluid Vaporizer(IFV), Using either water-glycol mixture or propane along with water for cooling [15].Or the Open Rack Vaporizer utilizing simultaneous air and water to heat the LNG to ambient condition [16]. These arrangement are to prevent structural damage, better control of process and offsetting environmental impediments [17].

Secondly, there are new method and techniques employing wide range of utilities like steams, direct heating by burning NG, looped heating systems and many more. These methods tend to be applied on onshore regasification facilities with robustness and versatility compared to offshore FSRU. There accessibility and reach allow for integration and applied focus on optimization comparatively. So they are an efficient means for energy optimization of the process like the cold energy utilization in industrial park [6] or poly-generation in power plants [3].

In continuation to utilities, there are multiple hypothetical and real time utilities with various considerations. Natural gas, an excellent fuel and source of heat is used directly in a fired heater to heat the LNG to desired temperature and condition. Simultaneously, a waste heat stream from other industrial complex or power generation may be used to heat it with cost saving for fuel and complex capital expenditure [18]. Furthermore, there is steam streams produced on-site, can be either High Pressure Steam (HPS), Low Pressure steam or medium pressure steam depending upon the duty and cost parameter. These steam with each having a variable cost. Since, with multifarious utilities are working in conjunctions or hybrid models to reach out a feasibility plan and cost optimization usually an objective of the process [12].

The ascertaining of goal-based objective is a complex and herculean task, in order to pragmatically reach a solution, various software models are used. In doing so, there is a better generalization of process and understanding the variability of process under the changing dynamics [17]. Here our focus will be on using Aspen HYSYS for modelling the various utilities and structural considerations, with sets of inherent tools meeting the process parameters.in order so PRSV (Peng-Robinson) model is used in calculation of real-time models.

Since all these models are based on data values compiled from previous research papers, feasibility reports and .The incoming LNG is stored at atmospheric pressure to prevent any sudden expansion, leading to a hazards [19]. And typically the composition of LNG is a mixture of various lower hydrocarbon mixture influenced by their colligative properties [20]. The primary components being methane, Ethane, Propane, Butane, Pentane and Nitrogen gas [8].Hence the typical model here is utilizing an optimum 500 MMSCFD gas with sole focus and variability introduced in the vaporizer. As mentioned previously, which is varied structure and models like IFV, ORV, Shell and tube heat exchanger, updraft or natural heating towers, multi-stream plate exchanger or others [21]. Thus, the utilities are determining type exchanger application in process. Moreover, the LNG batches composition varies according to location and processes involve effecting liquification parameter like boil-off gas and others [22]. Thus, average established criterion is used to weigh in on composition [23].

Table 1-Composition of LNG [9]

Composition	%
Methane	85.60
Ethane	7.8
Propane	2.9
N-Butane	1.9
Pentane	0.3
Nitrogen	1.5

Moreover, this process entails various utilities, each utility setup being a unique and distinct other than preceding it [24].In order so, there variability is subject to flow rate, heating requirements, heating value, duty and heat contents. Also, the pressure and other factors significantly impacts the heat transfer allowing for the heating. This extraction of heat content from utilities also involves many potential phase changes due to the physical properties of substances. Besides, the sensitivity of process lies in the handling of ultra-cooled cryogenic fuel gas, which are prone to hazards and damages. Thus, this consideration seriously limits options availability in this process to achieve safety standards.

In spite of long history of LNG usage in commercial usage, it has remained relatively safe and accident free process to date [25]. Due to extreme level of precaution and prudent standard along with little to no human control has corroborated in this proven track-record. Moreover, the ultimate research with contentious utilities and structure are also pivotal in this regard. Thus, the commercial viability and safety feature predominate the ultimate criteria [26].

1.2. Motivation of study

Pakistan since the last two decades has seen a significant drop in production of domestic natural gas production along with an exponential rise in demand due to the rising consumption by industry and population alike [27]. It is impossible to plug the demand supply gap without importing 0.8-1.2MMBTU of LNG [28].And, it is the only short term solution to augmenting the gap of supply side. Apart the cheaper alternative of pipeline transportation are available like the Iran-Pakistan pipeline, Turkmenistan-Pakistan pipeline through Afghanistan [29]. But these projects have been subject to geopolitical factors inhibiting the development.

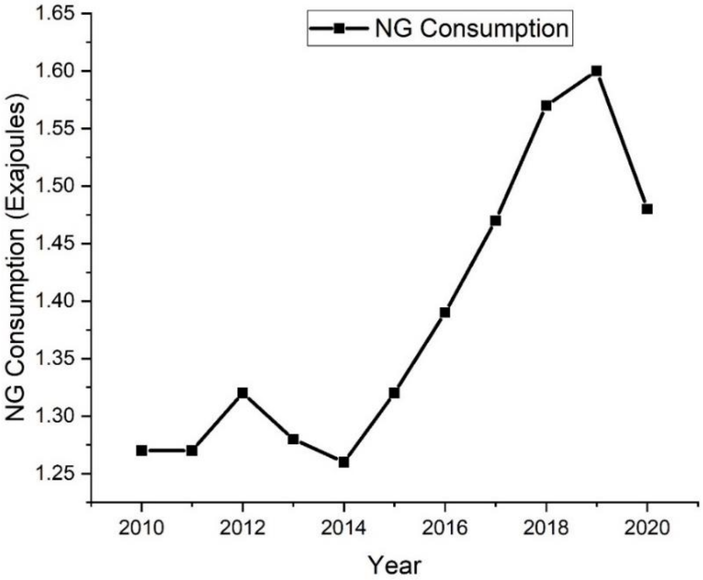


Figure 1-NG Consumption in Pakistan according to B.P statistics 2020 report [8]

This surge in demand was accompanied by a shortfall in domestic NG production. thus, a crises situation developed triggering industrial relocation and energy crisis. In such dire circumstances LNG is the only option to maintain equilibrium and avoid a crisis. With a daily demand of 1.8 MMBTU, Pakistan imports up to 1.5 MMBTU from Qatar [8]. There are two FSRU Terminal along with an onshore terminal for the regasification [28].This B.P statistical review report demonstrate the rising imports of LNG, since 2015 it first introduction in Pakistani markets. Moreover, most of this gas is procured by floating open tenders and the biggest export to Pakistan came from Qatar.

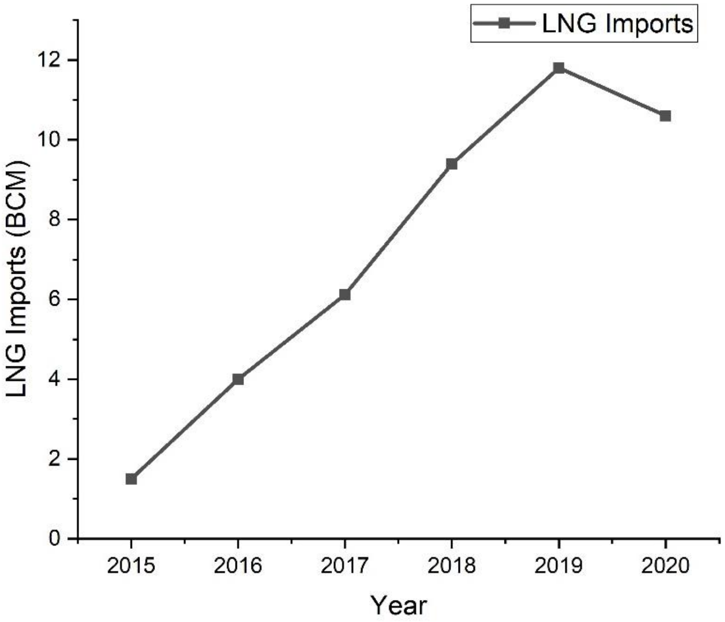


Figure 2: Yearly LNG Imports of Pakistan by BP statistics report [8]

As mentioned previously, the wide usage and deficiency compelled Pakistan to import LNG. In this, Pakistan uses offshore liquefaction plant mounted on ship with storage known as FSRU due to their readily installation and operational parameters. In this pursuit, there are many innovative and financially viable alternative either onshore or offshore construction utilizing a range of utilities and structural modules. They recycle or reutilize energy in this employing an environmentally and financially sound practice. simultaneously, there has been little of research and development endeavor coupled with industrial activities in Pakistan. These collaborations are an essential to feasibly and economically beneficial alternative identification, it is a step to accountability, transparency and credibility of using public exchequer.

1.3 Objectives of study

Our focus and prime objective in this endeavor is to study various alternative gasification models in context of Pakistan. For this study our objectives are as follow:

1. Techno-economic analysis of LNG Regasification Alternatives.
2. Understanding Operational variability of LNG regasification alternatives in Pakistan

Chapter no. 2

2.Literature review

With spurred economic growth and increased industrial activity worldwide, has fomented a chain of fuels as a necessary prerequisite for these activities. Since, the world energy demand is increasing by 1.2% year [8]. Natural gas is a mixture of low boiling hydrocarbon ethane, propane, methane, butane along with minute impurities like hydrogen sulfide and ethylene and others.   Thus, natural gas being a clean and low carbon fuel has promoted its versatility and robustness. Indeed, the energy security along with consideration of national interest is also a phenomenon here. This marked shift in fuel is also a product of technological improvements and low cost associated with it. Hence natural gas has emerged as an efficient, cost-effective and environmentally good, also is 24% fossils fuel used as of 2019 [30]. Thus, the natural gas usage boosted because of stricter environmental regulation, cheap price than oil, energy security away from OPEC, and cleaner fuel awareness [27]. The boiling temperature typically ranges from 166 ˚C to 157˚C at atmospheric pressure, and the density is in the range from 470 to 430 kg m^3, both depending on the exact composition [25].

Natural is a moisture of hydrocarbon primarily composed of methane, but also contains Ethane, Propane, and other heavier hydrocarbons. It is produced as either part of crude reserves or reserves from ground basins. This chart demonstrates the natural composition [24].

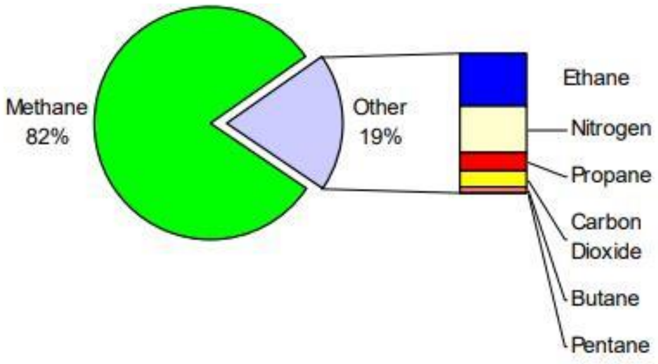


Figure 3-NG Compositional Chart [18]

Moreover, the LNG composition somewhat resembles this but some non-Methane component are removed in order to prevent them from solidifying while liquefying methane [31].

As mentioned previously, the grim situation risen out of extreme fossil fuels usage, with no contemplation for environmental, more particularly the high carbon, sulfur and other pollutant levels in environment have raised alarm. Due to abundant fossils fuels usage, they continue to be 85% source of power. Besides, the global CO_2 production is to increase by 30 % from 2030 to 2005, even with improved efficiencies and renewable use, it is a beat case scenario [32]. Natural gas, thus a cleaner and efficient fuel, due to comprehensive purification processes. Compared to the coal used previously being promoted as alternate to coal for short term basis. Due to its relative low carbon with gradual paradigm shift to renewable and sustainable energy resources in the long term solution.in order for long range transport of natural gas, Liquefied natural gas is a better and feasible alternative to transport by pipe [33].

Liquefied natural gas is a cryogenic liquid of paraffinic hydrocarbon with carbon range from C1-C5 [33].While, LNG is made from cryogenic cooling of natural gas by Joule Thomson effects and successive expansion, compression and cooling [34][35].This liquefaction of natural gas is a highly energy intensive process, due to high rate of compression and cycled recirculation. Since, the energy intensive process is preferred over the transmission through pipeline or other means .meanwhile, pipeline transport is the cheapest and most feasible alternative, but it requires large scale infrastructural investment [9]. Also, it is deemed fit for shorter distance and population scattered over large territory. It is basically long-term investment and time consuming for the infrastructure development. simultaneously, the operational cost, and maintenance cost are minuscule comparatively. Hence, the LNG import is comparatively expensive than feasible pipelines.

Liquefied Natural gas is product of highly energy intensive process employing joule Thomson effect involving compression, cooling and expansion. The expansion liquefies the Natural gas, which is cryogenic liquid requiring special storage and handling. This process reduces the volume by about 600 times [36].

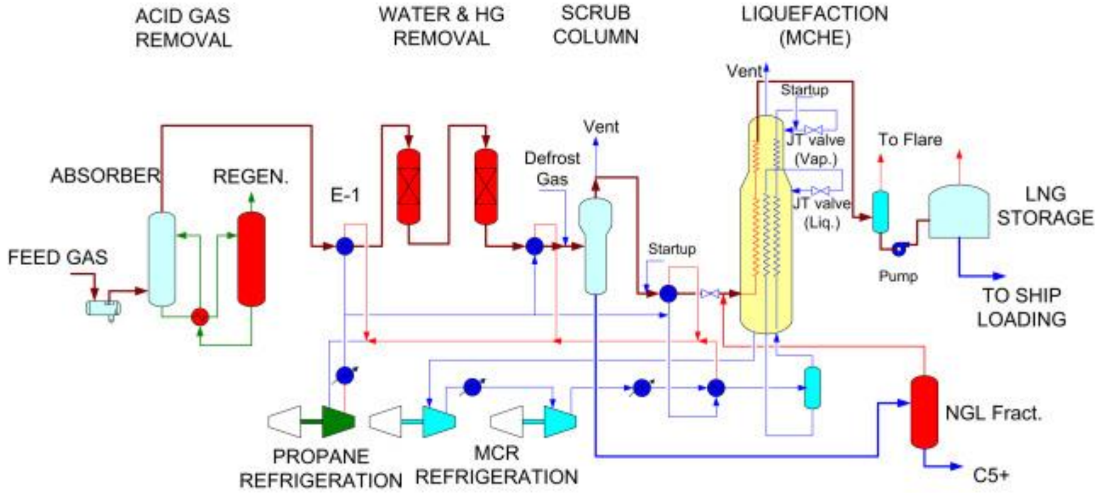


Figure 4-Process Flow Diagram of LNG liquefaction process [37]

This process flow demonstrates about the pretreatment of gas and stage wise removal of different impurities. With further the incremental cooling and liquefaction of gases, these gases are stored at shipping decks to load and transport them to the destination. The transport and storage processes approaches closed system in behavior. Thence, the LNG has assumed foremost importance due to energy security and vitality to security and national interest of Pakistan [38].

Simultaneously, the tanks are generally of a double-jacketed design in which the inner jacket is made of stainless austenitic steel and the outer one of carbon steel. The space between these jackets is filled with perlite and the jackets are under vacuum, which ensures high quality insulation. The maximum stored LNG volume should not exceed 90% of net tank volume [39].

As mentioned previously amount the significant resources involved in conversion of form and transportation. moreover, no rigorous and systematic model exist to optimize and rationalize the whole process.in this paper, the writer depicts energy and environmental analysis to quantify chain losses, emissions and wastes. Much of the research cycle has been focus on lifecycle of NG from kimet at al., foss et. al and other. There primary focus has been on crude calculation and models to optimize [2].moreover optimization models for robust and sustainable calculations are widely available characterized as stochastic and deterministic [40].

Constructing reliable simulation models for all the processes creating up the chain create several challenges like current natural philosophy limitations (vapor-liquid [6] equilibrium) and flowsheet convergence. Building credible simulations additionally need the employment of sensible equipment/ method envelopes and constraints that limit the program output to predictions that are reflective of real-life operations. Identification of those envelopes and constraints will be challenging because of the complexness of the system. Mary et al. tried to converge and develop comprehensive models by dividing process employing hold and cold sections. The efficiency was calculated using thermal efficiency as the ratio between energy in usable product to feed and fuel LHV (Low Heating Value) power [3].

Efficiencies of the main NG processing units ranged from 94.07 to 99.9% with the liquefaction being the least efficient process, a high efficiency demonstration of physical state conversion. The utilities were found to be the least efficient process with an efficiency of 31.4 and 21.8% during holding and loading modes, respectively. Loss primarily due to additional flaring of BOG. Also, the total fuel needed for 2.2 MW/MMSCFD of NG to user, with a production of CO_2 amounting to 14 ton per MMSCFD equivalent to 14 % Carbon in NG feed. Compared with oil refinery for same energy output they amount to 20% more. In this whole process the regasification only has 4% stake. NO_x amount 0.5 per MMSCFD and SO_x 0.08 ton per MMSCFD gas [1].

The pipeline systems are divided into transmission, gathering and distribution systems. There are three major types of pipelines along the transportation route: the gathering system, the interstate pipeline system, and the distribution system. Gathering system is composed of low pressure, small diameter and corrosion resistant pipes due to mercaptans and H_2S in gas [9]. Transmission pipeline systems transport natural gas thousands of miles across the world to bring natural gas from the pre-processing plants or storage facilities to distribution systems. Distribution pipeline systems can be found in communities and distribute natural gas to homes and businesses. The main differences among these systems are the physical properties of the pipelines used, such as diameter, stiffness, material, etc., and the specifications of the maximum and minimum upstream and downstream pressures [41]. There are also several other type of system of compressor along the transmission line connected in series or parallel. They keep on providing the required propelling force by minimizing the impacts of an inevitable pressure drop, due to frictional losses [7].

Natural gas demand is continuously increasing due to a growing appetite of nation, due to its environmentally safe and sustainable nature along with a comparatively low-price chart. According to USA EPA, the demand, supply and reserves of natural gas is continuously increasing and its projected to increase up to 40% by the year 2035 [42].Currently, the federation of Russia is the biggest producer and transporter of natural gas. Evidently, the Middle Eastern, euro Asian and north African countries are also taking a lead. This annual growth rate of 1.7% coupled with very high reserves has made a fuel of choice. The OECD and non-OECD report an annual growth rate of 0.9% and 2.0% [42].This phenomenal rise of change is a marking associated with wide technology use and transportation [6].

From the first appearance of LNG terminal in 2005, they have grown sustainably all across the globe. Currently there are more than 25 Export terminals accompanied by more than 91 import (regasification) working or under construction terminal either onshore or offshore worldwide. This demonstrates the wide adaptation and versatility of this process to secure the ultimate energy security in this regard. Moreover from 2005 to 2012 the volume of LNG traded grew by whopping 52 %. And Qatar the biggest producer of LNG has wooed to upgrade and increase in production to 60% in the next 5 years. All these significant factors are an offshoot of the burgeoning demand of the natural gas and LNG in particular. Also, there is subtle change in market and price of LNG year around, due to high demands and coupled with drop in production during the cold weather around world.

With Covid-19 surge the LNG supply chain grew by a 0.8% lower than the global average of decade 6.8% or 14 BCM [8].

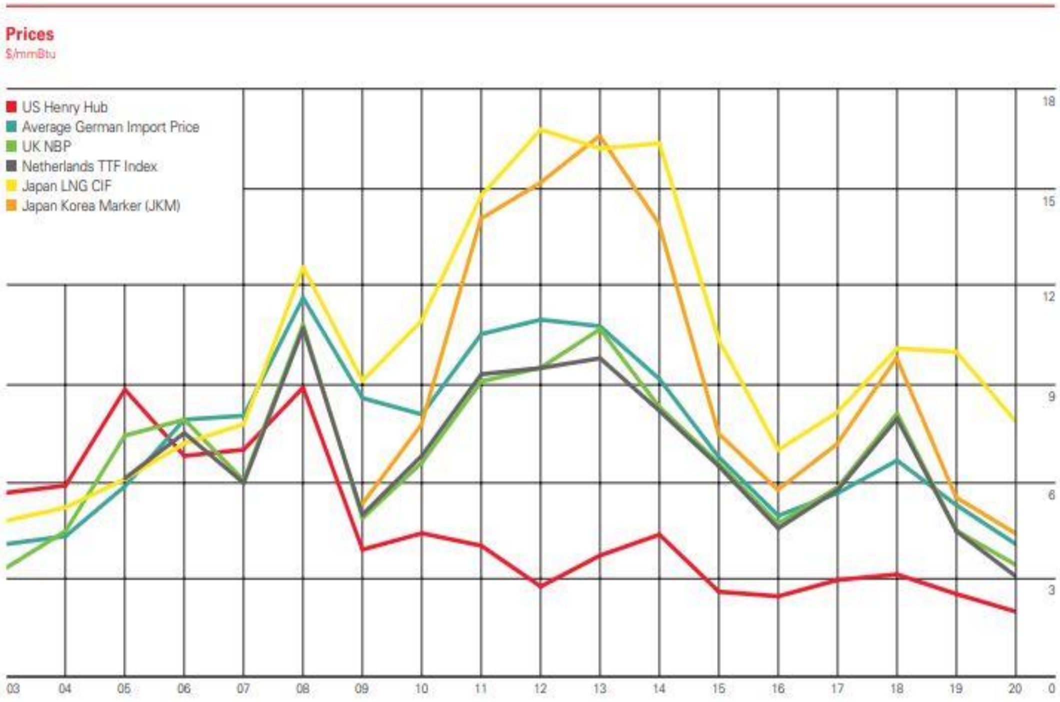


Figure 5-LNG Annual Global Price Chart demonstrating the fluctuating trend in price [8]

There is no denial and understatement of LNG technology in achieving sustainable growth along with environmental concerns. The technological conversion of NG gas to a cryogenic substance allows for the substantial volume reduction, though making the transport easier and feasible through container, which wasn't the case for gaseous state. In many instances, LNG offers greater trade flexibility than pipeline transport, allowing cargoes of natural gas to be delivered where the need is greatest, and the commercial terms are most competitive. The figure-6 below shows that as the distance over which natural gas must be transported increases, usage of LNG has economic advantages over usage of pipelines. In general, liquefying natural gas and shipping it becomes cheaper than transporting natural gas in offshore pipelines for distances of more than 700 miles or in onshore pipelines for distances greater than 2,200 miles [9].

However, there are cost accompanied with a comprehensive emission in this capital-intensive process. The abundance, affordability and availability of fossil fuel coupled with an emerging demand is the necessity for its robustness and versatility. The extremely short-term outlook for this installation and operation of RLNG plant anywhere in world makes it versatile. There are offshore ship plants with storage capacity and regasification. Just requiring a connection to transmission line and ready to deliver the natural gas to consumers. The initial capital cost is also lower compared to long-distance pipelines likes the NORD stream costing €14.7 [43].

The competitiveness of an LNG project is defined by the capital costs of the liquefaction plant and also by upstream gas supply and LNG shipping costs, which can significantly strengthen or weaken its overall dynamic competitiveness. LNG projects seek to maximize profit and minimize volume and credit risk preferring LNG buyers [44].

Large reserves of Natural gas are found in nation, with little or no demand and resultant markets. Such stranded markets are in Mozambique, Malaysia, Singapore, Middle East and others. Hence the natural gas is liquidized at such location for markets with high demand and little production to meet domestic needs. The cost parameter can be better understood by the analysis of choice of LNG over pipelines in term of cost and distance. Claudio describes the shipping cost amounting to $1/MMBTU from Canada to Asia [42].

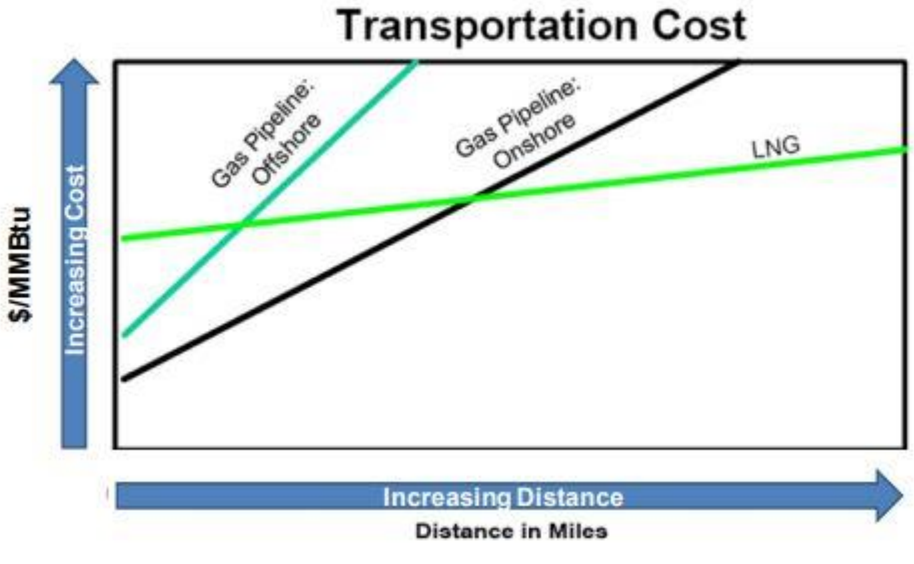


Figure 6-Comparative cost pipelines and LNG over distance [42]

The outlook of the relative share of natural gas transmission is demonstrated through this graph in figure-6.

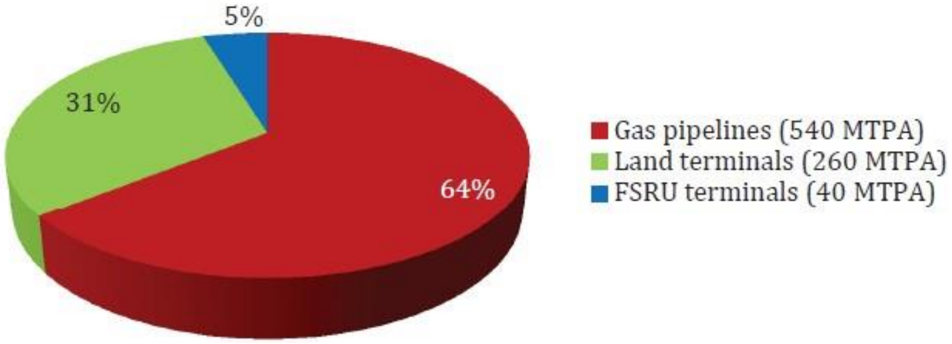


Figure 7-Share of Natural gas Transportation by means[9]

The use of NG is advantageous because NG has the lowest emissions per released Joule of energy among all fossil fuels reported Kumar et al [10]. Reported that CO_2 emissions from stroke engines running on NG dropped by around 20% and by 80% for NOx. Natural gas demand has risen recently as a result of stricter emission controls, delegation of production, lower prices than petroleum products, decreased scarcity as a result of the search for a substitute to OPEC-driven prices, and a general feeling among citizens that greener energy sources are required globally. Large amount of energy is spent in liquefaction of NG, which can be ultimately recovered in regasification process. LNG contains about 870 kJ/kg of energy [45].

The FSRU vessels are particularly suitable for opening smaller or inaccessible markets, The LNG transport ships deliver liquefied natural gas, which is transshipped to the FSRU vessel [14]. The regasification system (REGAS system) is the main functional system of each FSRU terminal. The site conditions such as sea state and sea water temperature can be deciding factors in the FSRU design. Therefore it is not normally possible or economically feasible to make the FSRU design applicable to all site conditions [46]. The capacity of the vaporizer system governs the whole FSRU performance. The LNG vaporization is done by the heat from the sea water. Instead of open rack vaporizers (ORV) used in onshore terminals, shell and tube type vaporizers (STV) may be adopted for the floating environment. The vaporizers should be designed to have uniform flow and operated at high pressure of about 100bar. The unloading time is approximately 12 hours with the unloading rate of 12,000 m^3/hr. [47].

Safety and security are very vital citing the significant combustibility and high capital cost associated with plant. All these are a manifestation of a relatively volatile operating parameter instill a sense of better caution and vulnerability. Cryogenic burns, similar to frostbite, can occur [48].Long-term inhalation of vapors or cold gas can harm the lungs. Colorless and odorless and thus undetectable to human senses. As a fuel gas, it is highly flammable with a lower flammable limit (LFL) of $4*10^5$% by volume in air and an upper flammable limit (UFL) of about 15%, depending on temperature. From the point of view of government, LNG storage facilities must be protected against intentional damage (sabotage, terrorist attack) and these issues considered in planning land use and energy infrastructure. Also, there are various failure mode apparatus installed to limit the scale and possibility of damage [19].

Failure Mode and Effect Analysis (FMEA) method is used for analyzing a process and identify possible failures, their origins, and their consequences on the framework. Specialized insulated pipe along with a very discrete and strong storage containers. In the storage tank there are numerous safety systems and alarms to reduce safety issues such as roll-over and evaporation. Low and High level measurement, level alarms ,Rollover alarms ,pressure transducers , and many sensors and control system relieving any accident and failure [49].

Currently the global regasification capacity stands at 852.3 MTPA , out of which FSRU maintain 115.5 capacity [4]. Onshore and offshore regasification differ in range of parameters, onshore being more flexible and accommodating than the former. Due to the capacity for expansion and remodeling due to availability of space and operability. Also, the storage capacity for onshore terminals is more along with a high regasification rate. For instance, the regasification terminal in Malaysia installed by PETRONAS, one being an offshore FSRU.

Terminal while other being the Onshore. The FSRU terminal is equipped with IFV , with unloading rate of 10000m^3/H and a storage capacity of 130,000m^3.while , the onshore regasification facilities employing ORV have a loading rate of 13000m^3/hour and storage capacity of 200,000m^3 [15].

The low initial cost of FSRU systems for importing natural gas isn't the sole benefit. The following are the important facets for considering FSRU[50]:

a. Constructed and commissioned in two years as opposed to four years for land-based terminals

b) The construction of ships in shipyards lowers the potential for cost and schedule overruns.
c) Cheaper for small, seasonal, and/or intermittent markets
d) Adaptable, with the ability to be shifted as needed to meet market demands
e) Less reliant on proper access, building limitations, and inland regulations
f) Providing faster access to an energy source, enabling fuel switching • supplying remote regions with LNG as an inexpensive and greener fuel than other fuels
g) Accessible on brief charters (2 to 5 years) and long-term charters (10 to 20 years)

However there weakness lies in a number of factors [50]:

a) FSRU regasification capacity are moving upwards, they are limited by smaller LNG storage and send out capacities, restricting their appeal to smaller niche markets.
b) As the demand for gas at their site location develops, it will be tough to expand or extend. This may be a matter of perception rather than truth, given the capacity of the gas export pipeline limits both FSRU and onshore regasification terminals. Additionally, additional FSRU vessels can be ordered to increase capacity.
c) Due to the harsher sea environment, they are bound by strict maritime rules and maintenance requirements.
d) Onshore facilities have more buffer storage (spare capacity) in tanks, which might be a disadvantage when market demand is unexpected and extremely variable.
e) Reliant on highly skilled personnel (maritime operatives, and more specialist, offshore process engineers in the vessel design and engineering phases)
f) Weather disruptions and downtime are a risk (if docked outside of sheltered port regions).
g) Although such facilities are currently installed onshore near to a jetty where required, space is limited to add nitrogen or LPG blending facilities to alter the calorific value of the send-out gas.
h) FSRUs are more expensive to operate per unit of capacity (charter day/rates for FSRUs are typically 2 to 3 times that of LNGCs) [50].

FSRU are the flexible and mobile offshore plants catering for national need. This has led to rapid rise in their usage since the commissioning of first in 2005. By 2020, they reached more than 40 plants operating in different corners of world. Currently there are two FSRU berthed in Karachi meeting the demand of Regasification needs [51]. They come with variety of Vaporizer setups employing a wide array of utilities. Mostly ORVs are used but now IFVs are getting common nowadays. The energy integration processes are unlikely due to complexity involved in FSRU and limited space.

The site conditions such as sea state and sea water temperature can be deciding factors in the FSRU design. The FSRU's available plant space is extremely limited, compared to conventional onshore receiving terminal. Floating vessel and process facility safety aspects, including mooring, collision, capsizing and other process features characterizing the process [50].

IGU 2020 publications compared the capital costs of offshore and onshore regasification, demonstrating why FSRUs are becoming more popular. Unit capital cost for onshore regasification was US$334/ton of capacity in 2016 (compared to US$ 242/ton for a similar average in 2015) and is predicted to reduce to US$212/ton in 2017. In comparison, the same for FSRU 2016 was US$78 per ton of capacity (against US$158 in 2014). New build FSRU vessels with greater pressure tanks are unlikely to cost less than US$100 per ton [4].

The effects of inlet LNG mass flow rate and pressure, as well as inlet seawater temperature, on heat transfer coefficients and needed heat transfer areas of the thermolator, evaporator, condenser, and entire IFV were explored in this study. There is no icing or frosting problem, there is a minimal requirement for saltwater quality, there is a low carbon emission, and there is less vulnerability to ambient circumstances, among other things. Furthermore, because to its low capacity and indirect heat transfer, the IFV is ideal for the floating storage and re-Gasification unit, as well as the cold energy recovery system. an evaporator for vaporizing the intermediate fluid with a heat source fluid, and a condenser for releasing the intermediate fluid's latent heat [52].

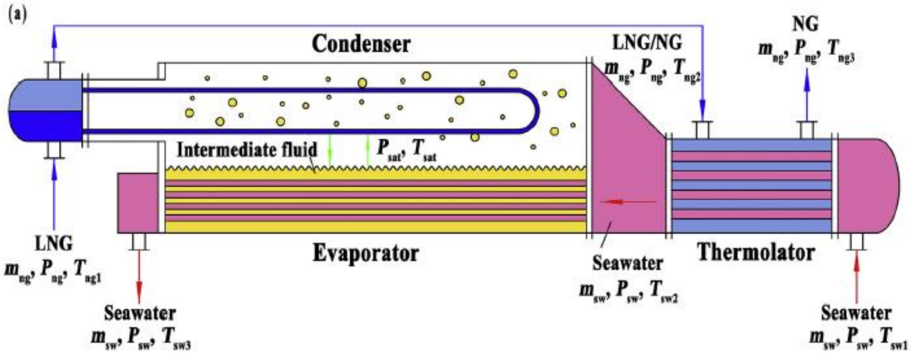


Figure 8-. Schematic of the heat transfer process in a typical IFV [52]

Recirculation, depressurization, and unloading are the three processes in the process of discharging liquefied natural gas (LNG) from a carrier ship to a storage tank. The cryogenic temperature allows for recirculation to keep the pipeline cool in order so to prevent LNG vaporization and pressure surge in pipe. Originally, two type tanks: Above-ground and in ground Tank. Pipelines are depressurized matching the inlet pressure of storage tanks [53].Offshore LNG storage involves hazard due to movement of vessels and BOG generation involving roll-over challenge

During the regasification operations, it was predicted that roughly 47,214 and 88,383 kWh of cold energy might be obtained daily at RGTPJ and RGTSU, respectively. For the 20-year life cycle of a project, transforming this energy into RTh at 70% thermal efficiency and using the market rate of 0.549 Sen/ RTh, a return on assets ratio (IRR) of up to 33% and 17% was forecasted for RGTPJ and RGTSU, accordingly [15].

Chapter no-3

3.Modelling and Simulation of LNG Re-gasification Alternatives

3.1 Process Description

Liquefied Natural gas (LNG) is a cryogenic liquid made for shipping on long distances onboard a Shipping and storage container. This liquefaction is a highly energy intensive procedure aimed to create market in energy deficient countries. This cryogenic fluid requires 600 times less volume but handling and storage problem and requires with further treatment at destination to be able to be used. This treatment meted involves careful vaporization of the LNG fluid for the distribution to market or consumers [7].

This process entails a loading and holding modes like any other alternative aimed at vaporization of LNG. When the LNG storage ship is berthed at terminal, insulated pipeline is connected to maintain flow rate with the simultaneous recirculation aimed to maintain pressure in the process for the safety and preventing sudden vaporization which may lead to accident due to sudden expansion. After the flow is pumped the storage on ship is purged using the nitrogen gas [53].

The flow from storage ship is stored into spherical double layered insulated storage tank [5].while the ship is disembarked the process continues under holding mode with the gas capacity stored already. A low-pressure submersible pump pushes the liquidized natural gas into stream, while the vaporized fraction is separated from the trop. In this, the top vapor from the storage tank is subdivided into flare, recirculation loop and to the compressor. The flare is installed to prevent excess buildup of pressure exceeding the design limitation, leading to accident. Moreover the major chunk of vaporized stream 2 is moved to compression in a 500KW compressor [12]. After compression the stream moves into re-condenser (in ASPEN HYSYS model which is separator) the expansion of compressed gas along with the contact with cryogenic LNG condenses the stream. Next the liquid at the bottom of re-condenser is pumped through a high-pressure pump to vaporizer of different utility and structural configuration. For use, the LNG is vaporized and warmed to a temperature of about 5˚C then fed to piping at a pressure of 2-6 bar [19]. It may be transported as a compressed gas in road tankers or used as fuel in ships. The selection of an optimum vaporizer type for a given LNG receiving terminal depends on the plant site location, climatic condition, throughput capacity, demand fluctuation and operating flexibility, etc. [5].the series of different utilities and process configuration are mentioned here:

3.1.1Seawater heated system

In the water heated LNG heating system, it's the application of seawater as heating medium to vaporize the fluids. Sea water has properties varying across region and times of years due to changing profile of temperature, salinity and others [54]. Hence, the benefits associated to some regions are high compared with other geographical regions. These variating parameters can be better understood by observing the profile of seawater and entailing conditions.

This addition of heat is usually done in a countercurrent exchanger, which is pressure sensitive along with higher rate of heating due to extensive heat transfer area [54]. Besides, this gradual profile change of LNG prevents any accident and water freezing in process. With simultaneous, it also involves a low log mean temperature difference and high utility flow can be accommodated compared to feed to be gasified. In this ASPEN HYSYS LNG vaporizer is used from the model palate.

Sea water intensive properties along with the contemplation of outgoing parameter of natural gas vaporized are highly dependent. With the temperature parameter of outgoing line gas varying across the world from 0-25˚C. The higher temperature output involves temperature crossover, or a lower log mean temperature varying across the world determinant to a limiting factor. Moreover, this requisition also involves the water freezing, fouling rate, salt deposition of the tube and other surface area. Thus the service and maintenance cost and operation are a stumbling block [46]. Also, the wastage of cold energy output from this devastates marine biodiversity causing a temperature profile change (temperature shock). Furthermore, the water in closed loop can also be used to provide refrigeration like a chiller to proximate facilities. Enhanced configuration like ORV’s and others are commonly used instead of enclosed shell and tube exchangers, along a very high-pressure requirement.

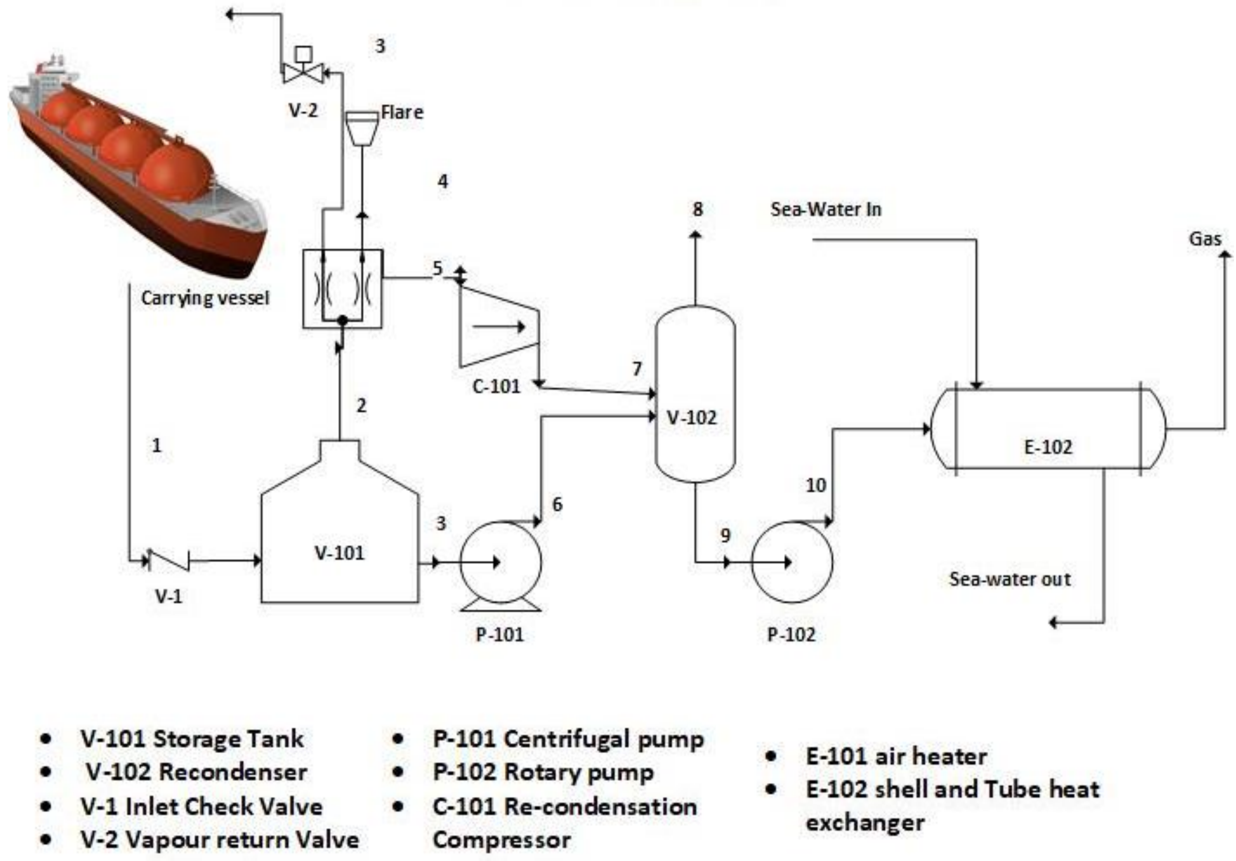


Figure 9-Seawater Heating system (ORV)

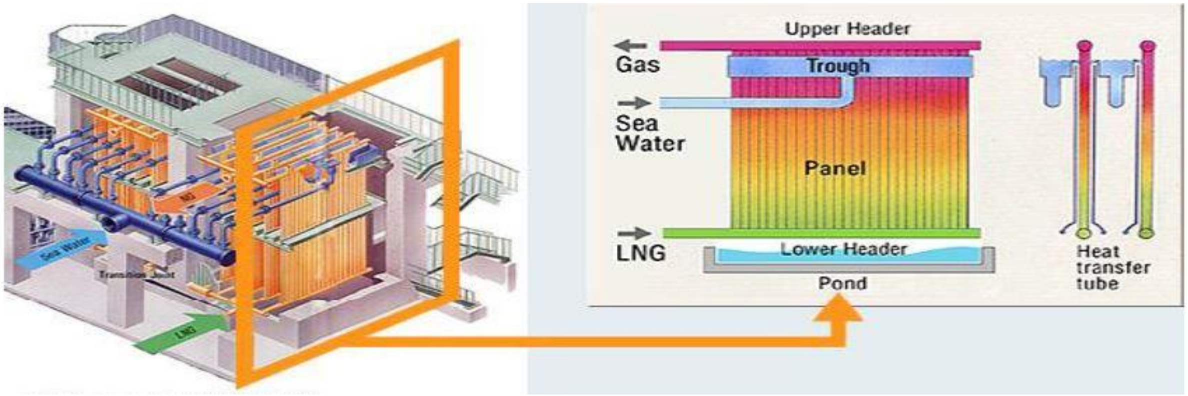


Figure 10-Open Rack Vaporizer utilizing water to heat the LNG to re-gasify(a)Bird eye view (b)cross-sectional view of ORV [6]

3.1.2 Ambient air Heating System

This system utilizes ambient air as heating parameter in large scale heating towers. The heating properties of air have lower heat capacity with corresponding low heat transfer rate and density. These miniscule properties of gas or air compared to fluid indicates a major setback to their use. Since, in the air properties the most profound effects on heat transfer are absolute humidity, dew point temperature, particulate matter and others [55]. Moreover the air parameters are variable, with robust changes year around as opposed to the water properties which change gradually.in addition, Air side fouling depends on a number of factors on the air side, including type and concentration of fouling matter, size of particles in the fouling matter, and air velocity.it is mainly comprised of particulate fouling, precipitate fouling, chemical reaction fouling , freezing fouling, corrosion fouling and biological fouling [56][40].

The air heated system comprises of natural or forced draft heaters. With air as medium of exchange requiring a comparatively high flow rate subject to extreme fluctuation year around, either reducing or increasing the fluid vaporization. However, it can also lead to cloudiness and freezing of liquid at heating interfaces depending upon the humidity. Also, there is also a great effect of fan speed and no. of fans in forced draft which can be evidenced later with data. Since, this process also involves a very high pressure drop, due to the large area required for achieving the gasification and successful heat transfer. Thus making these heater very large and spacious with little or no utility cost complimenting cost saving but simultaneously high maintenance cost [57].With many merit and demerits along with technical limitation will be studied here.

For the demonstration of LNG flow DHE plate and fin heat exchanger with forced external flow will be heating the LNG medium to account for the change.

In this setup we are utilizing a forced draft heating tower with 4 fans with RPM of 500 to prevent freezing of humidity on heating surface. The no. of fan utilized, and speed greatly influence the resultant condition, which will be demonstrated later. Moreover, these factors also dictate the size of air heater. Subject to temperature of air which fluctuates, we have base temperature of 25° C in Karachi, while we also understand the behavior output condition with the changing conditions.

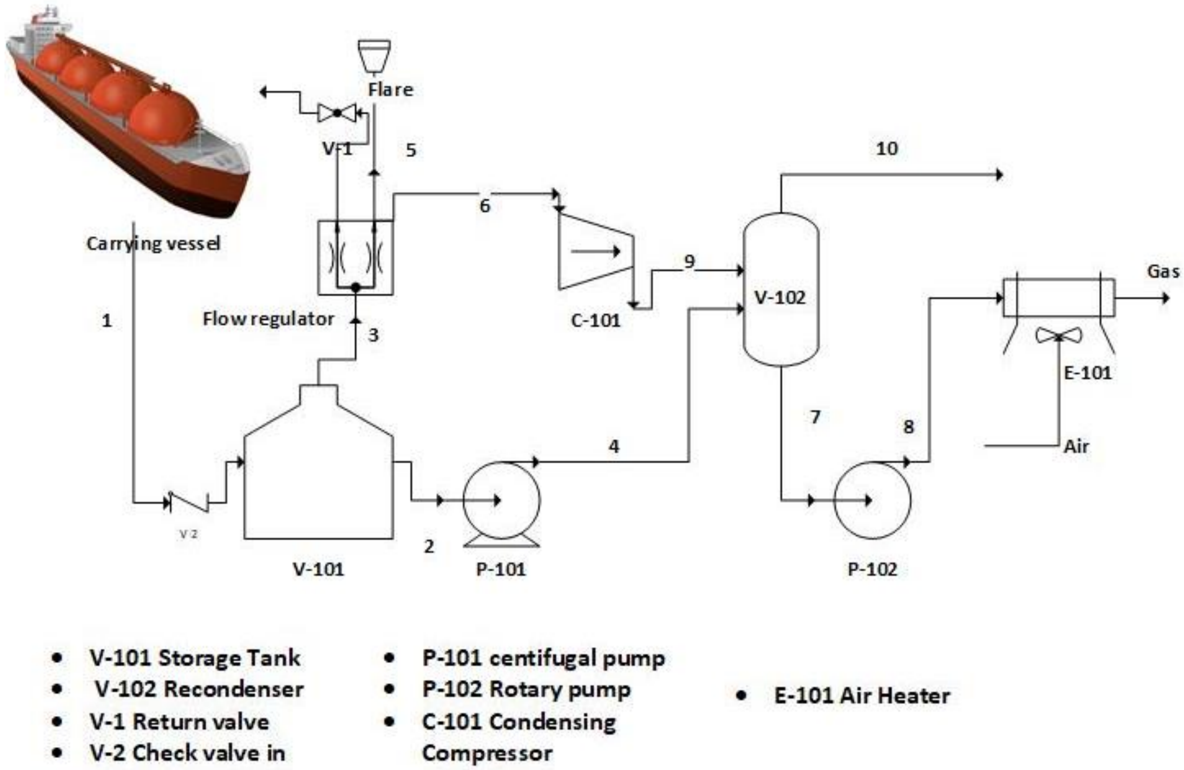


Figure 11-Ambient Air Heating unit

3.1.3 Integrated Series Water and Air system

This construction model involves a closed or open water loop with a transient air system heating the LNG to produce natural gas. This system overrides the problems inherent in the previous two models like the freezing, high surface area. This process demonstrates the applicability of simultaneously air and sea water heating.in this loop the input requirement are adjusted to offsets the parameter resisting efficient operation.

This simultaneous application of seawater to LNG to obtain a required temperature without cross-over and high LMTD correspondence. The sea water and air stand temperature stand at 25˚C base condition. Thus, the required duty is passed through two different exchangers in series. With the first latent heat conversion in sea water-based shell and tube TEMA exchanger. Subsequently the air heating in forced heating towers meets the aims to desired conditions. Also, the output conditions of utilities are adjusted and optimized to point, where to avoid any systemic and safety failure. Like the freezing, fogging and others. Simultaneously the role of temperature variability is also studied relative to output conditions and, suitable structural and properties parameters.

The high temperature and pressure parameters before the process allow for significant pressure drop reducing the output to a 1000 KPa which is sustainable for the piping and transport, beyond which the transmission and transport is not feasible depending upon the pipe dynamics and build quality [58]

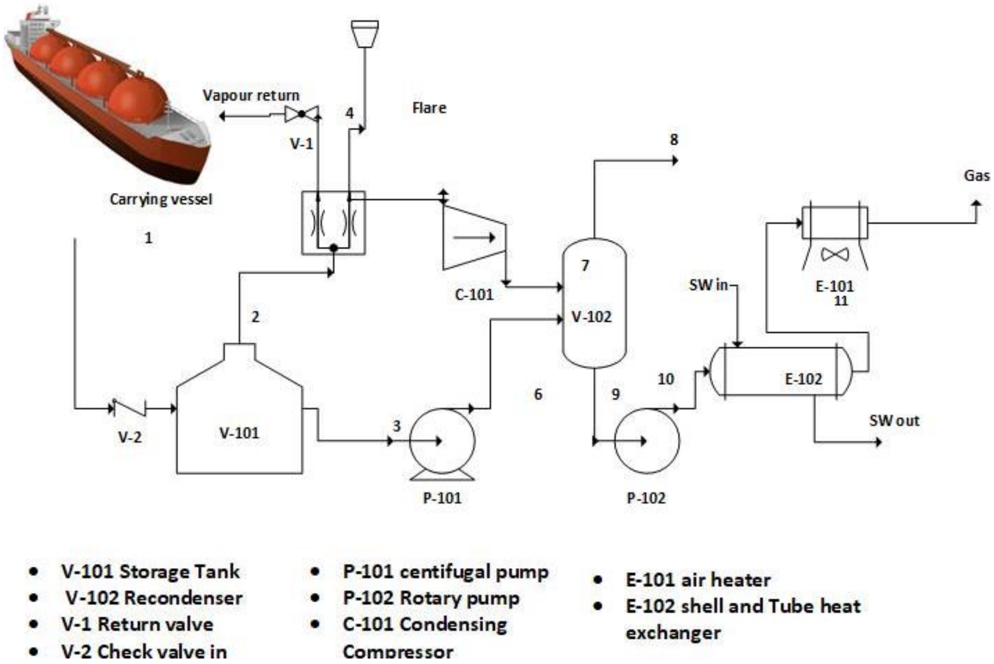


Figure 12-Integrated Series Air and Water system

3.1.4 Integrated Parallel Water and Air system

This model is a preferred choice in arid and dry regions of the world due to it utility requirements and high versatility of it [3].This methods and structure employs a combination of water and air as a utility to remove the cold from the LNG. The latent heat and open structure allow for better safety features with enhanced focus to energy utilization to achieve the requirement. This process occurring achieves a natural equilibrium to necessitate the requirement. Moreover, the extreme weather event like blizzard, or cold temperature are a stumbling block to it utilization in semi-arid region like Pakistan, it is a common and easy choice without many intricacies.

For this purpose, in Aspen HYSYS, with PRSV equation mode we utilize LNG vaporizer and customized to our requirement in necessary module. Thus, the temperature parameters are observed for air and water temp variability along with substantial focus also on the LNG output temperature in form of gas. The entailing study would also compliment the necessary variability of the parameter intrinsic to atmosphere, like water, temperature, air temp and output gas characteristics.

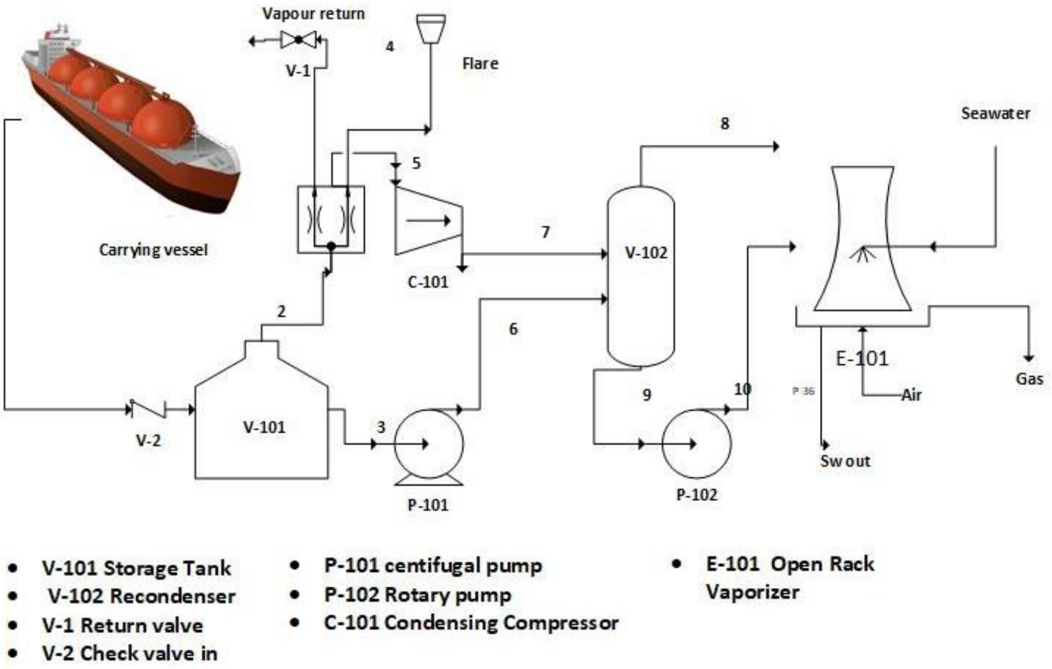


Figure 13-Integrated parallel Water and Air Heating system

3.1.5 Fuel Gas heating (FG)

3.1.5.1 Direct heating system

In this module a natural gas stream from the outgoing gas is burned in a fired heater, which is translated to the heating of the LNG and the resultant conversion to gas at a required temperature and pressure. The heating is radiative in the process, with pressure drop, efficiencies close to optimal to generalize on the condition. The air is ambient which is pressurized to 200KPa to excess quantity to compliment the complete combustion and heat transfer flow. This process utilizes 0.2 percent of flow ratio of LNG gasified. Moreover, this process doesn’t compliment the required line pressure, hence to moderate pressure, an expander is employed.

The effect of change of temperature in output is related to heat duty, LMTD, flowrates and dynamics of process. This along with many other will dictate the efficacy of process. The insight dictates the prevalence of natural gas and air flow influence the change in the output temperature. Overall, this scheme is least dependent upon on atmosphere and has more freedom in process itself. But the safety, economy and vulnerability of this process are a negative factor to its choice.

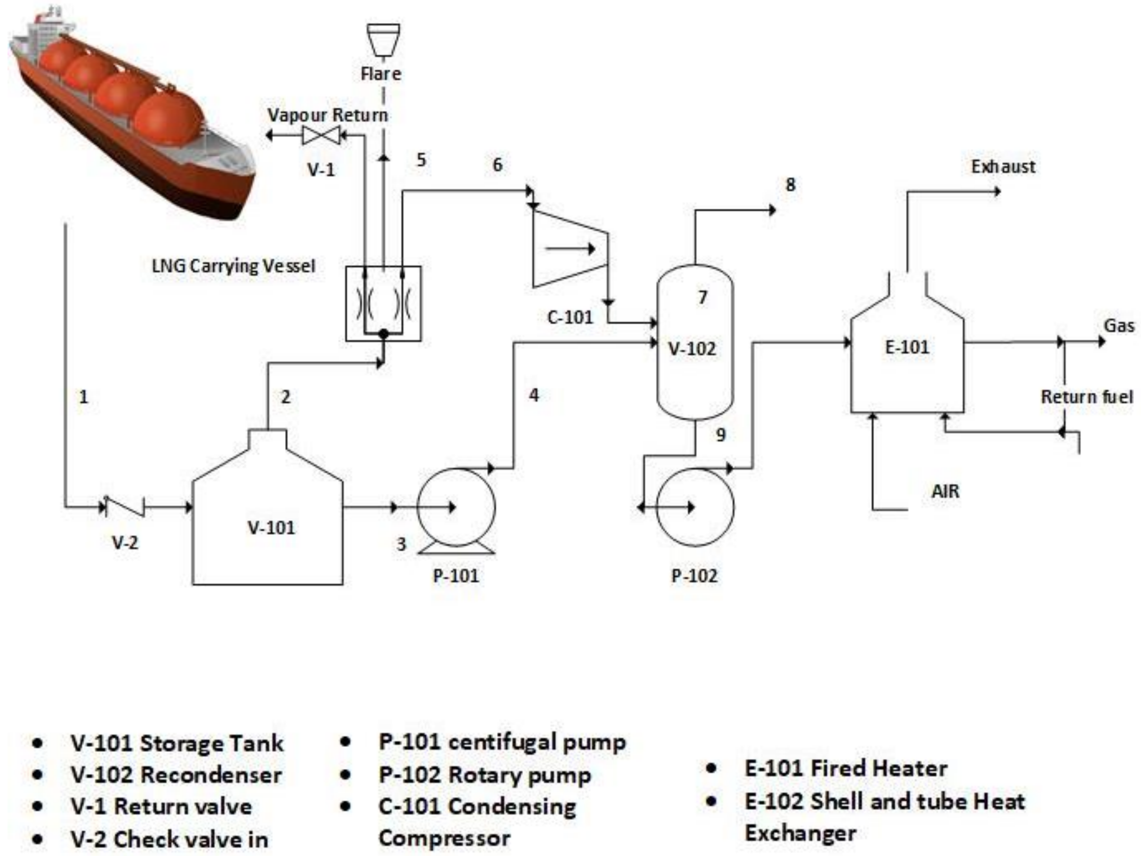


Figure 14-Direct Fired Heating System

3.1.5.2 Indirect fired heating

This process is close to direct fired heating but involves a medium to safety and intermediate heat transfer mechanism. Being analogous and proximate to submerged combustible vaporizer employed utilizes water to transmit the heat to LNG. This heat transfer primarily is completed in counter current TEMA Shell and Tube heat exchanger in which the flow is in counter current. While the water temperature significantly alters in tandem with the natural gas flow rate along with the air quantity. The air is usually provided in excess of the required to complete combustion of process and achieve the maximum heat extraction from the process. The fire heater employs the same 0.02 % of natural gas flow, while the heat transfer here occurs mostly due to radiative energy.

Subsequently, the indirect heating like the direct is independent atmospheric variable and this high degree of independence utilizes the contours of a safety. Further, the negative attributes like the safety, vulnerability are compensated by the use of intermediate heat transfer process. However, the operating cost of atmospheric variable utility remains low, so such process is employed more to region with discouraging atmospheric conditions.

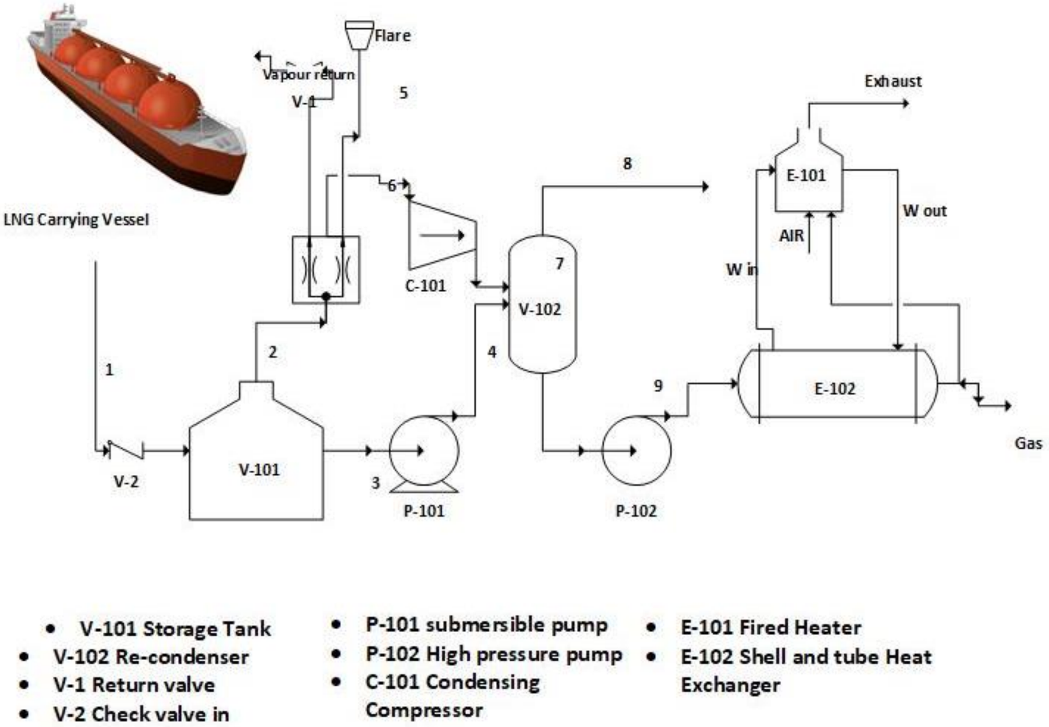


Figure 15-Indirect Fired Heating (SCV)

3.1.6 Intermediate Fluid Vaporizer (IFV)

Intermediate fluid vaporizer involves an intermediate fluid in closed loop extracting heat from a primary fluid or medium with no contact with the LNG. This series of step with customized equipment’s are performed in aspen using different exchanger dictating the overall cold systems [15]. The ambient conditions of atmospheric air and water are used to extract the heat from them. Making an intermediate prevents equipment maintenance and freezing and clouding problem as addressed previously [59]. Typically, the glycol-water mixture delivers heat in a shell-and tube heat exchanger. On the other side of the loop the mixture can receive heat from different heat sources, typically an air heater, reverse cooling tower, seawater, waste heat or a fired heater from a nearby industrial plant.

The advantages of an intermediate fluid vaporizer (IFV) include the better energy efficiency, less sensitivity to ambient conditions and no icing or frosting problem. This utmost robustness and reliability of this process is a demonstration of properties behavior of intermediate fluids used [52]. An IFV is typically a compact shell-and-tube heat exchanger with three parts, namely an evaporator to vaporize the intermediate fluid by a heat source fluid, a condenser to release the latent heat of the intermediate fluid to LNG, and a thermolator to heat the natural gas (NG) to the specified temperature before use. This system is comprised of two heat exchangers connected in series, with three different mediums to underscore and impel the required temperature level to be achieved. This demonstration in series is a modicum to present a complex IFV network. This system prevents the operational and maintenance hazard while the thermolator is essentially an optional section. It can be either integrated with the evaporator and condenser, or equipped as a standalone heat exchanger [14] **.**For this purpose there are relatively, three composures to IFV:

3.1.6.1 Propane-Seawater System

This system utilizes propane as the intermediate fluid (IF), while seawater serves as a heat source. Propane is a low boiling liquid, with properties varying according to pressure due to Boyle laws [60]. Here in this system the propane liquid is in a closed loop, pressurized to 1500kpa, which helps achieve efficient heat transfer. Also preventing the vaporization and cavitation in a system making it efficient and robust, while keeping the propane to temperature to avoid vaporization. This system however avoided the vaporization and condensation of closed loop medium. The utilization of propane is kept in a range to avoid freezing at upper range and vaporization at lower range [61].

This arrangement allows the use of seawater as low as 1°C, compared to 5°C with the ORV [62]. Furthermore IFVs are often more compact than ORVs, because there is no direct contact between cryogenic LNG and seawater [63]. Therefore, IFVs are often preferable when considering floating LNG terminals. The arrangement will often, but not necessarily, make use of the latent heat of condensation of the intermediate fluid to vaporize the LNG. Seawater is usually used to evaporate and/or heat the intermediate fluid on the warm side of the IF loop, as well as heat the NG after it is evaporated in the primary heat exchanger [64].

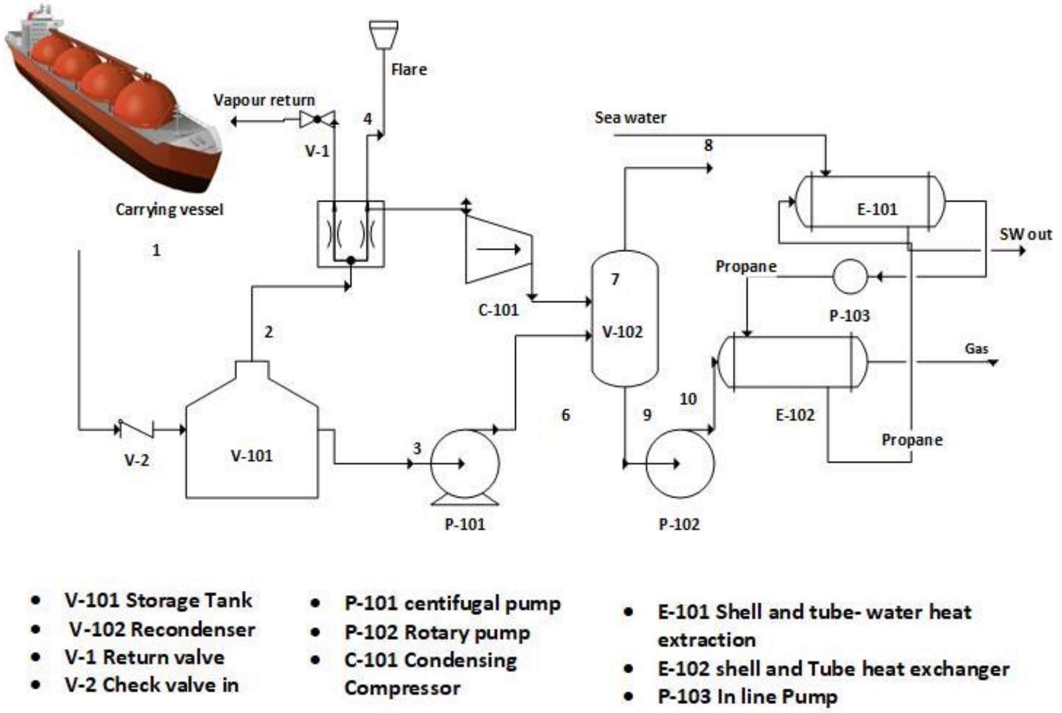


Figure 16-IFV Propane

3.1.6.2 Glycol-Seawater System

This system of IFV is within the same structural composure but requires a different intermediate heating medium. This use of glycol is further robust and versatile than the alternative hydrocarbons fluids used. The parametric properties of Glycol are broad ranging utilizing a very diverse range, with subsequently a safety aesthetics due to the hazard of high pressure or leakage. Glycol is 50 percent mixture by mass of ethylene glycol and water. Furthermore, this high range of liquid at super-critical and sub-critical level acts to presents a diverse applicability temperature range along with extremely focused temperature approach [63].

Moreover, the temperature variable parameter is the seawater temperature, which usually range from 34-15˚C in Persian Gulf. This variability can induce a change in flow rate, temperature and time, energy and others at output. However all this parameter for different LMTD, Flow rate Q, will be studied in this context [65].

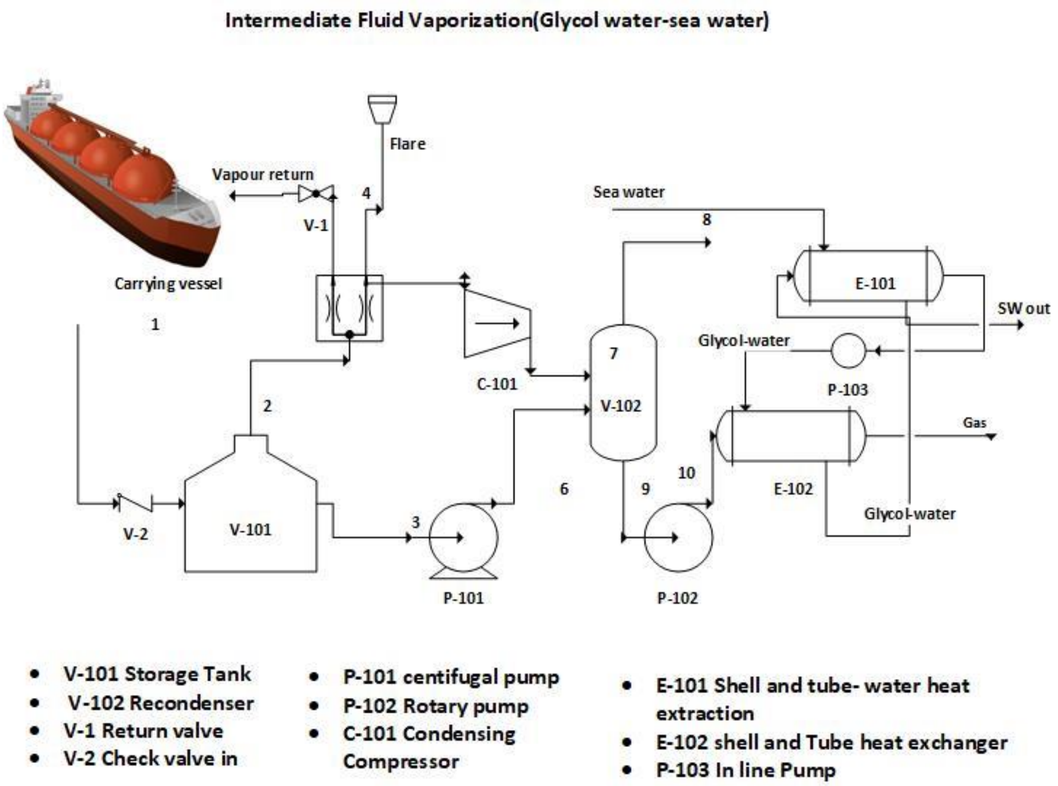


Figure 17-IFV Glycol

3.1.6.3 Glycol-Air medium

This operational structure is a variability to module of IFV used traditionally. In this instead of sea water, ambient air is used to heat the glycol, this heat transfer accompanied by a forced air cooler with 4 fans at varying speed. The extraction of heat from air is manifested itself in the wider range. Furthermore, the air temperature is manifested in the fluctuation and variability more often.

With an Average temperature fluctuating around 25˚C, the electrical utility is required to cool down the process into realization.in this this variability of temperature of air and a widespread natural gas temperature at output will also be studied to achieve a sense of understanding and complexity involved in the process.

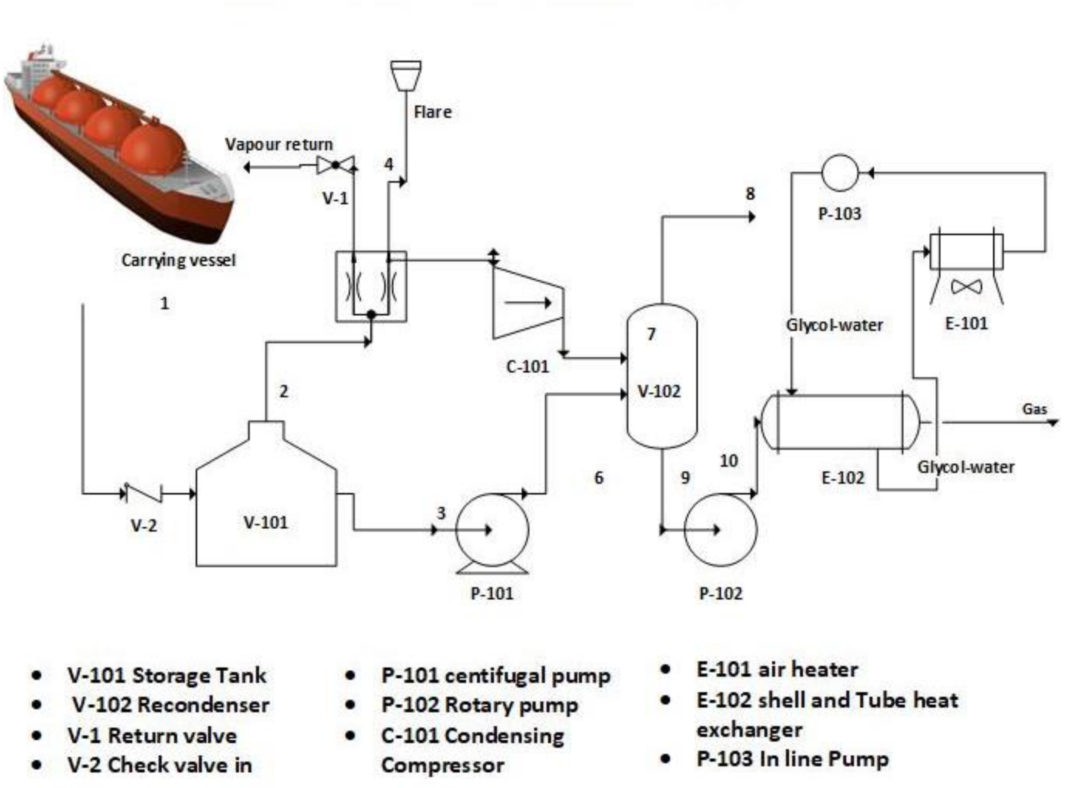


Figure 18-IFV Glycol-Air system

3.1.7 Utility Heated system

As industrially, there are many utilities available at plant site required according to wider conditions and a knowledge of requirement. For the purpose of heating there are many alternative utilities available, but the scenarios demanding are the high, medium and low-pressure steam in a process. These steams have a relative cost, temperature, duty and pressure.

This process is demonstration of how a LNG is passed through a tube side in shell and tube or double pipe heat exchanger depending upon the required output parameter required of the gas [64]. The TEMA Shell and Tube Heat exchanger is a better choice with a higher flow handling in conjunction with a lower capital cost. Since, this usage involves caution entailing a better alternative. Further, there are other circular parameter associated with the usage of particular utility upon the wider structural and parametric influence [66].

3.1.7.1 High Pressure System

The High-Pressure configuration employs a high-pressure steam utility in shell and tube TEMA heat exchanger. This heat addition from the steam at shell side converts the LNG to Ng. this pressure drop and temperature change are put task of reusability to process. The parameters of High-Pressure steam are 275˚C-14 bar, at the outlet to 250˚C. Like other alternatives, all these alternatives have similar process condition and flow parameter. The main variance stands in vaporizer and regasification [67].

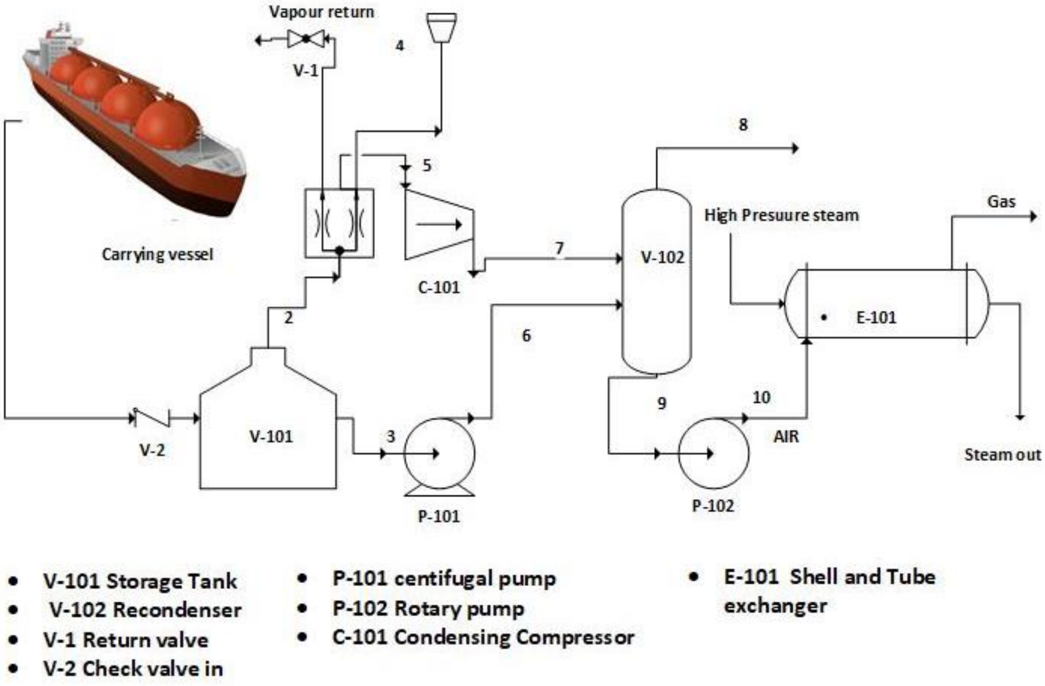


Figure 19-High Pressure steam Heating

3.1.7.2 Medium Pressure Steam

Medium pressure steam in the shell and tube heat exhanger require almost the same configuratrion.with a similar heat duty but the LMTD, flow rates and capacity strucrtural requirenments are different.the stream characterstics of MPs system at inlet 175˚C leaving the process at 160˚C.this amrked change in conditions resound the operational characteristics.as mentioned previously , like other utilities this process employs a shell and tube TEMA type Heat exchanger, with LNG in tube side accounting for any pressure changes hazaradous to the process [68].

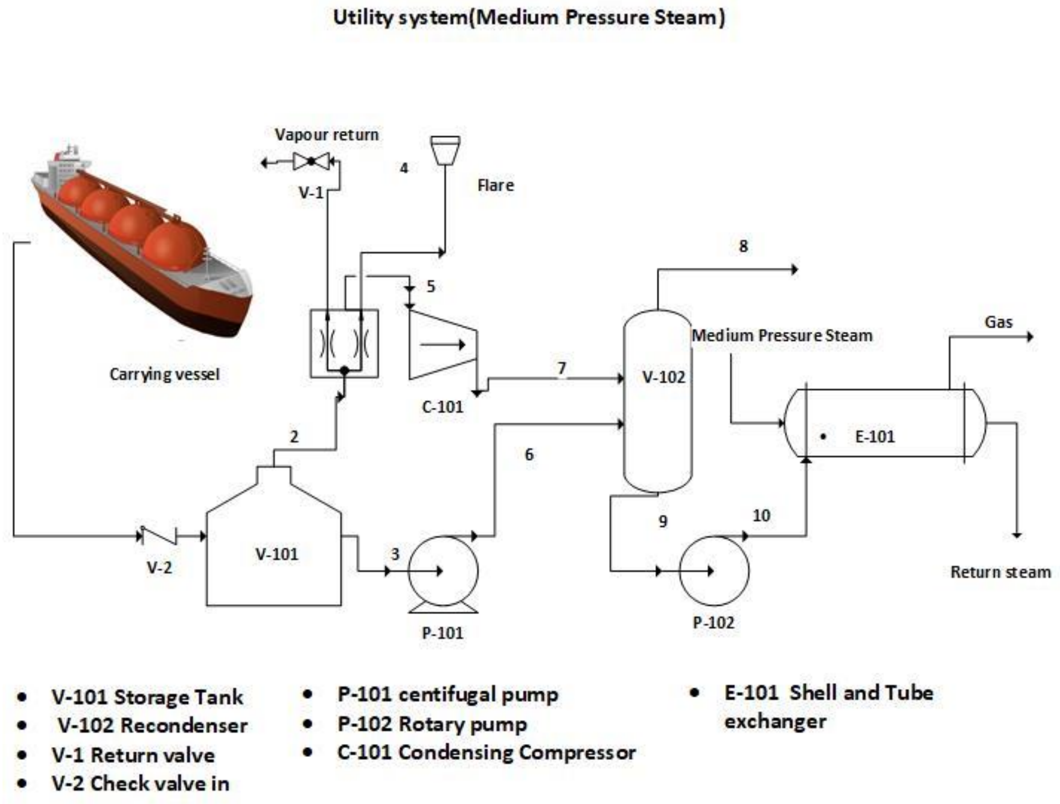


Figure 20-Medium Pressure Heating System

3.1.7.3 Low pressure steam

This system employs a low-pressure steam to account for the latent energy and state change of LNG. With its comparatively lower heating value and pressure automatically underlines the higher use with a comparatively larger structure. This configuration is congruent to, used for previous two utilities. The physical parameter of LPS is 100 ˚C 4 bar leaving the process at 99 ˚C.

The output conditions are an important determinant of the required utility and accrued cost.in this, the output temperature change over range is observed with a resultant impact upon flow rate and heat duty. Furthermore, the pressure is held constant at threshold value of pipe tolerance of 10 bar [41]. These properties as mentioned previously dependent upon the composition greatly influence the parameter studies. Similarly, this utility also utilizes the TEMA type Heat exchange in model in ASPEN HYSYS.

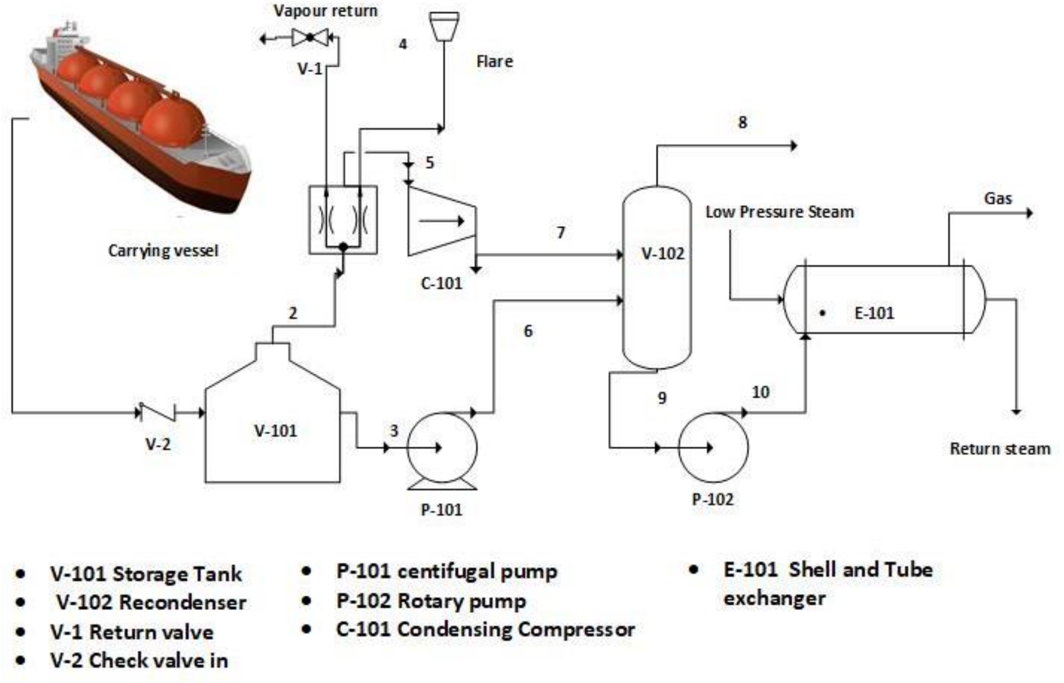


Figure 21-Low Pressure Heating System

3.1.8 Waste heat recovery

In this last process, the LNG is gasified by the continuous supply of a flue gas stream either from a power plant or other industrial combustion process. This flue gas from combustion has highly variable parameter employing high heat rendition and recovery. With all the resultant changes, the Osheaga plant in Japan experimented with this employed from power plant. The temperature exiting the burner was 870 ˚C which after pressurizing and resultant transmission suffered heat losses. These losses decreased the temperature to 470 ˚C [18].

Here in this model, the shell and tube exchanger will have a TEMA type, with LNG at tub side and flue gases in shell side heating Length pressure was accounted to host of factor, which was kept to optimized level of 1500KPa.in purview of the complex dynamic in this process, these imperatives in the system accounts for the substantial pressure loss to account for the change in state of LNG.

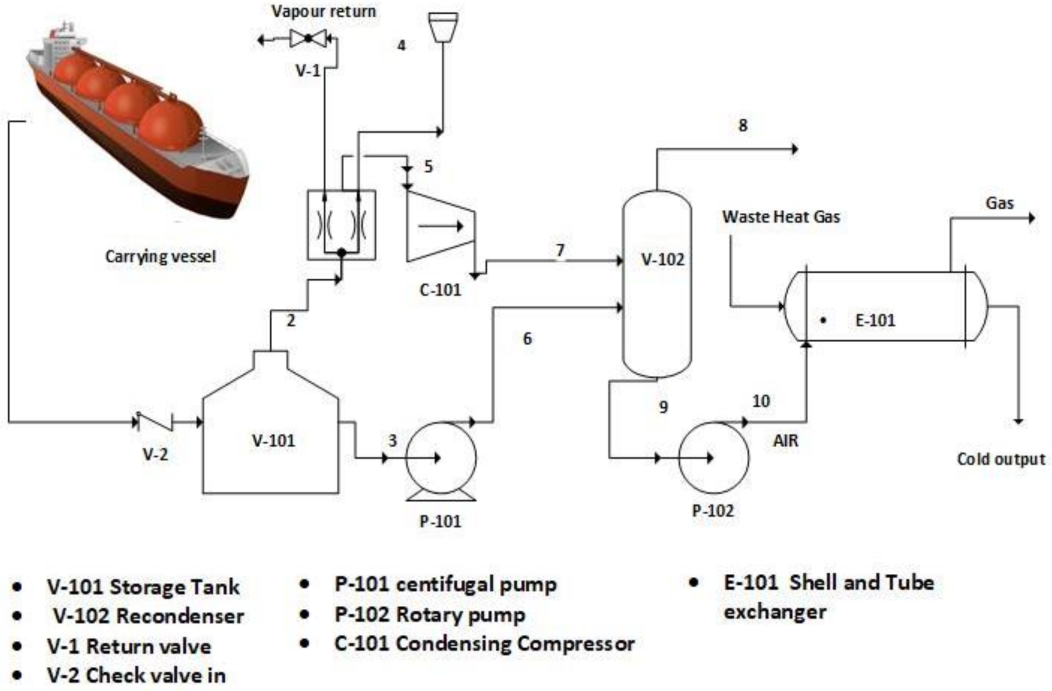


Figure 22-Waste Heat Recovery System for regasification of LNG

3.2 Process selection and optimization

The technologies studied in this study were chosen based on the idea that a simple design with little environmental effect is sought, with a simultaneous high energy efficacy and a compact structure. The goal is to find alternatives that can re-gasify LNG cost effectively and integrating energy. Alternative soundness posing the least amount of risk and leaving the least amount of environmental footprint, while still providing optimum dependability and electrical efficiency[18]. The contour or standard used to pre-select the most acceptable technologies is depicted schematically in Figure-23.

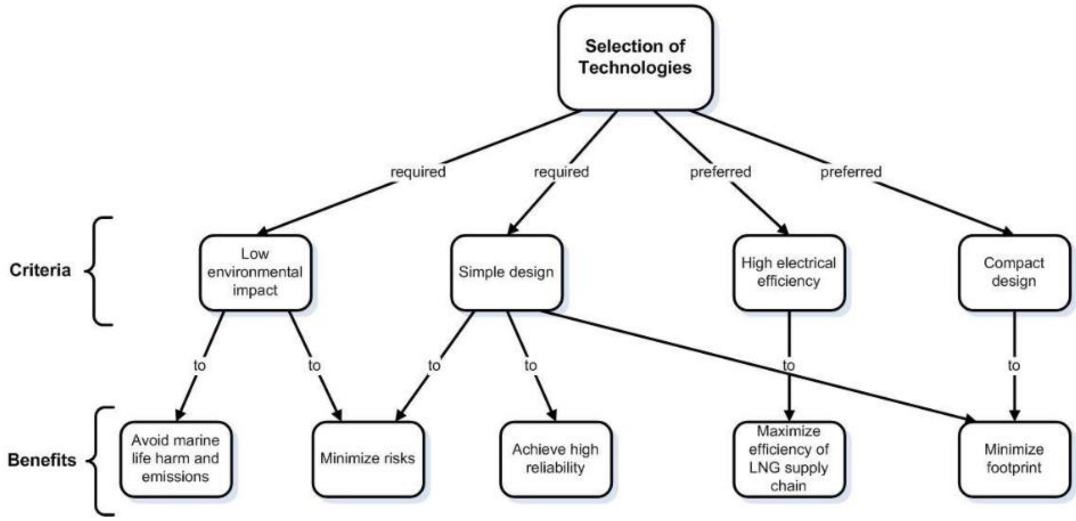


Figure 23-Selection Criterion for Process Feasibility

All these alternative will be analyzed and studied here to accord a semblance of process ingenuity to achieve higher degree of freedom and suitability to dynamic and constant factor inherent in domestic situation of Pakistan [69][28].

3.3 Modelling and Simulation

For the purpose of modelling and simulating the LNG regasification system, we used ASPEN HYSYS, with the plausible PRSV equation as base model. For the process parameter outlined in the process section. However, the main variance stands in utilities and structural configuration employed in the process. To this, we established the rates of utilities input upon the modelling calculation and for the rates of domestic utilities prices were input to establish the economical parameters. Fourier's law establishes correspondence with the mass flow rates and temperature differentials.

$$PV = nRT$$

The cubic PRSV equation of state represent nonpolar, polar non-associating, and associating chemicals equally effectively [70]. For a wide variety of binary systems, the traditional one-binary-parameter mixing rule allows the correlation of vapor—liquid equilibrium data [71][24].Peng-Robinson equation of state

$$P = \frac{RT}{v-b} - \frac{a}{v^2 + 2bv - b^2} \qquad 1$$

With

$$a = (0.457235\mathrm{R}^2 {T_c}^2/\mathrm{P_c})\ \alpha \qquad 2$$

With

$$b = 0.071796\mathrm{R} * T_c/\mathrm{P}_c \qquad 3$$

According to soave α is

$$a\ =\ [\mathrm{I}\ +\ \mathrm{K}\,(1\ -\ T_R^{0.5})]^2 \qquad 4$$

Simple expression for κ

$$\kappa\ =\ \kappa_0\ +\ \kappa_1\ (1\ +T_R^{0.5}\ )\ (0.7\ -\ T_R\ )\ .$$

Whereas,

$$\kappa = 0.378893 + 1.4897153\omega - 0.171318\omega^2 + 0.019655\omega^3\ . \qquad 5$$

However,

For the heat transfer calculation involved in this physical Transformation of LNG to gaseous state. Fourier’s law and Newton laws of cooling equation are an important undertake to establish a close to reality parameter.

$$\frac{dq}{dx} = -k\frac{dT}{dx} \qquad 6$$

$$Q = Mh(T_1 - T_2) \qquad 7$$

The parametric influence is characterized by the heat transfer coefficients influencing the heat transfer depending upon the type of fluid, state and density and other characterization influence. Moreover, the heat capacity of each fluid as a function of properties and temperature is also indicative of the changing heat carrying capacity.

$$Q = mCp(T_1 - T_2) \tag{8}$$

Moreover, logarithmic mean temperature difference signifies a real time approximation to overlook the parameter of heat transfer and establishing an empirical relationship. As for this process, the counter-current flow signifies an outlook demonstrative of the likely trend.

$$LMTD = \frac{\Delta T1 - \Delta T2}{LN(\frac{\Delta T1}{\Delta T2})} \tag{9}$$

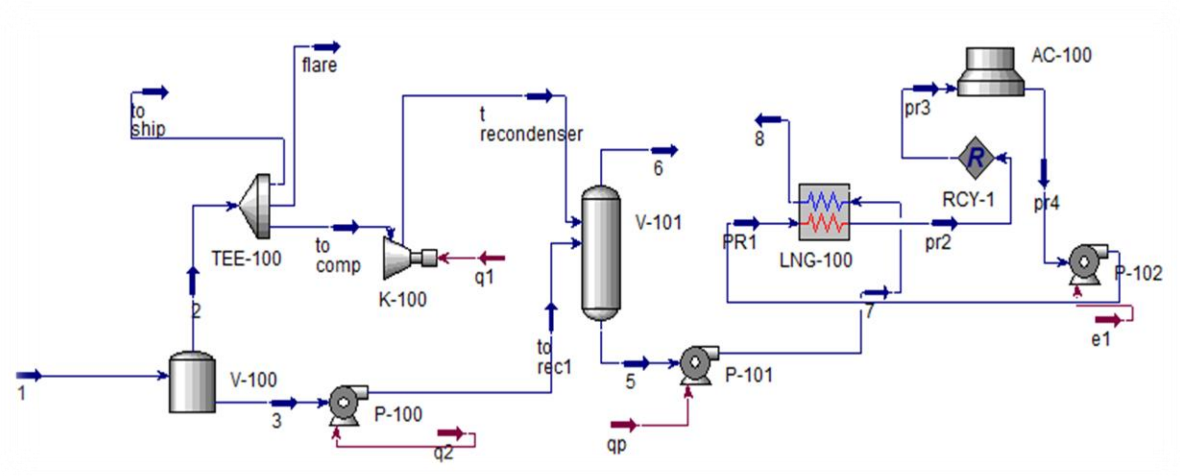


Figure 24-HYSYS Simulation OF IFV Glycol-Air System

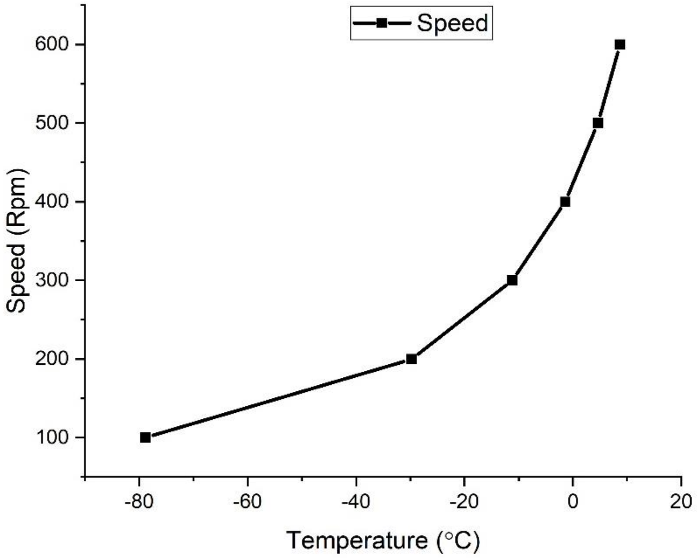
Chapter no-4

4.Results and discussion

4.1 Ambient air Heating unit

With the environmental variability of air temperature around the year and the likely volatility of air parameter. substantially, the number of fans in forced draft cooling tower and their relative speed has a crucial role in determining the performance of air heating and financial soundness of process.

Figure 25-Fan Speed vs Output air Temperature



This fan speed vs outlet air temperature graph demonstrates how by increasing the fan speed, the temperature of air at outlet can be increased. Initially, the straight increase trend is due to high heat capacity and large temperature difference between both medium.at a temperature proximate analysis depict a low air temperature change with a simultaneous change in fan speed at a higher LMTD [57].

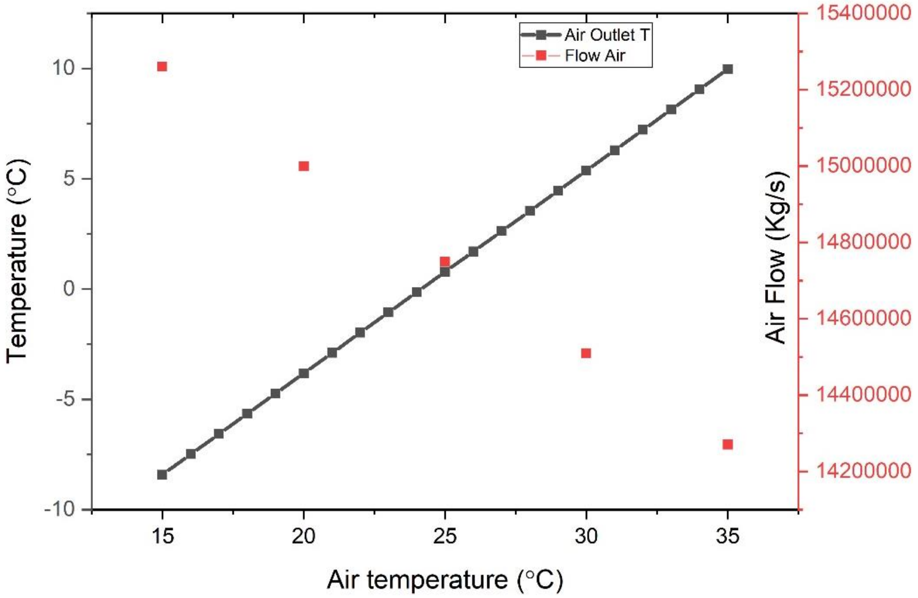


Figure 26-Air Temperature vs Required Air Flow and Output Temperature

In this air temperature variability graph, there is a likely increase in the flow rate to augment to alter the temperature under the relatively same degree of change in temperature. This direct increase in slope indicates of Fourier laws, vindicating the change in mass flow rate and temperature differences augmenting a steep change and higher transfer rate [57].

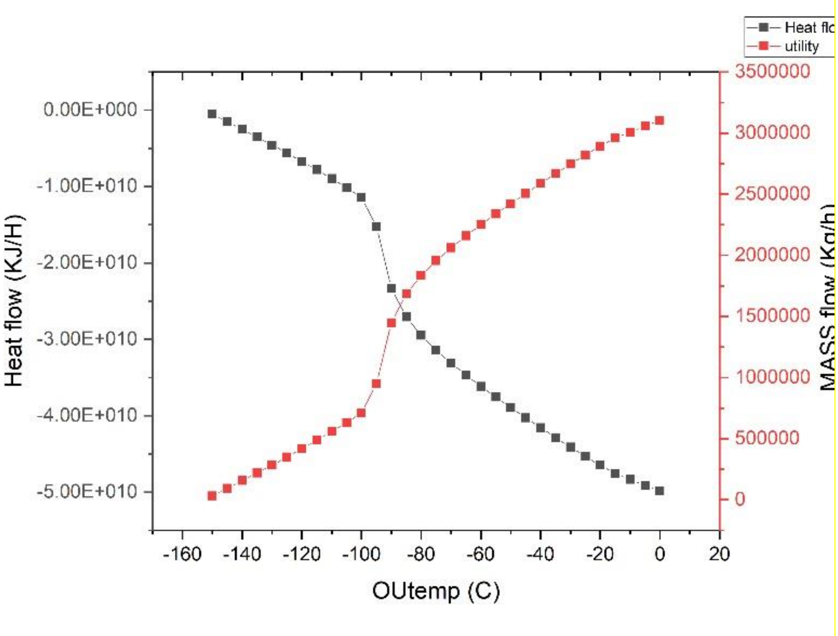


Figure 27-Variating output Air Temperature-Heat flow and Air flow

In the same manner, the graph is an illustration of outlet air Temperature vs heat duty and mass flow. This established relationship demonstrates how the behavior of the whole process will change in response to the outlet conditions. Furthermore, the break point in this graph indicates the influence of inherent properties parameter like heat capacity, phase heat transfer, heat transfer coefficient in confluence with variation and differences in the likely state. This augmentation of state is likely a factor describing the feasible operating ranges and a state of optimal operating condition. The lower the output temperature will promote a range of fouling and scale coefficient hindering heat transfer and pursuit of efficient regasification process.

4.2 Sea-water Heating

Sea water as illustrated utilizes sea water heat to effectively degasify the LNG. the temperature of seawater is likely to be different worldwide to due to location and relative environmental condition worldwide. Simultaneously, the salinity, and other factors are also influencing. Apart, sea water is most widely used heater, gas the operation of ORV is completely dependent upon it, which is an essential component of FSRU, commonly used re-gasifier along with many onshore facilities.

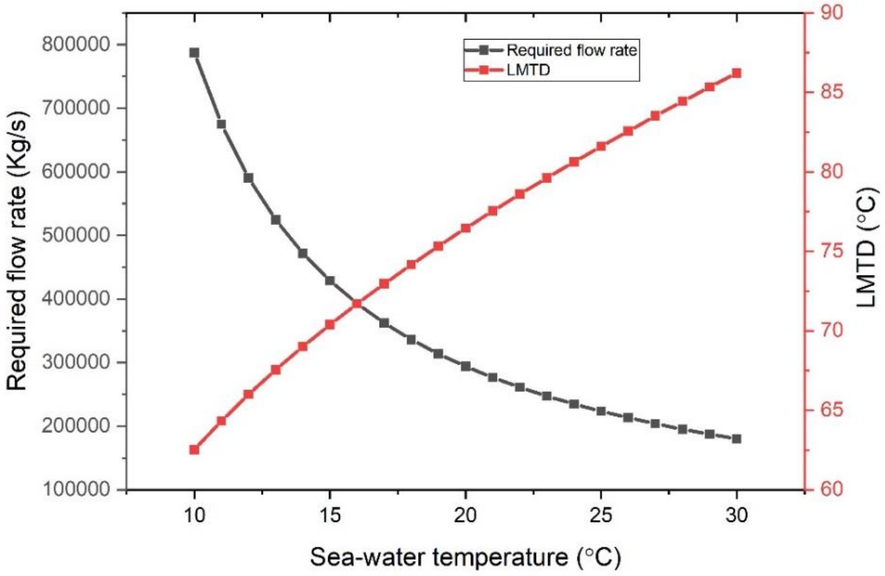


Figure 28-Annual Water Temperature profile vs the flow rate and LMTD

This profile of sea water temperature vs the LMTD and mass flow rate for a constant re-gasified natural gas temperature of 4℃. This trend is demonstrating that the steep decrease in the flowrate augmented by the rise in seawater temperature, with a simultaneous drop in the LMTD due to decreasing temperature. To account for, the greater temperature difference tantamount to a high energy flow and little mass flow rate in pursuit for optimum regasification temperature. Hence, all sea temperature and mass flow rate are inversely related [72].

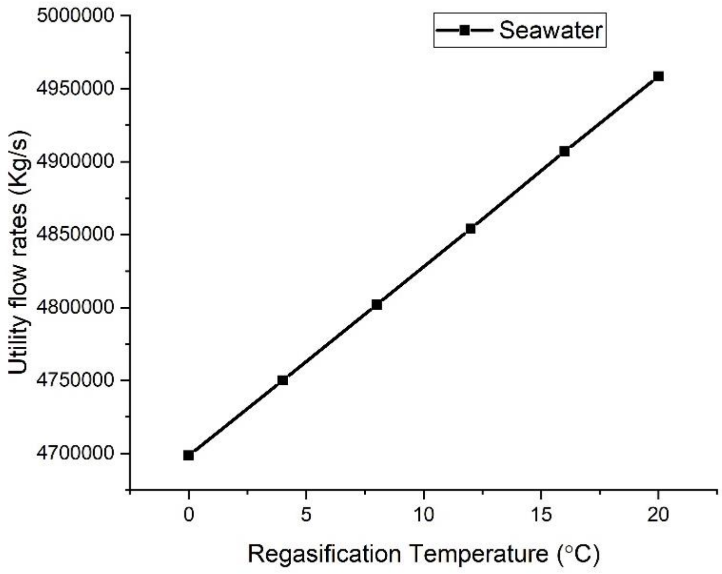


Figure 29-LNG gasification temperature vs required flowrate

Moreover, as can be seen in the graph depicting mass flow rate and output R-LNG temperature for various output condition. Thence it concludes the temperature range generalized flow rate and environmental accreditation employing the impacting condition across the seasons[67]. Also, the sea water temperature is much less volatile and prone to change than a ambient air heating system.

4.3 Integrated Parallel ambient Air and Seawater System

The simultaneous employment of seawater and air as heating system makes it a robust and efficient alternative for regasification. The impacts of relative flowrate are studied with output temperature of gas and the utilities. This substitution employs diverse containment in DHE plate and fin Heat exchanger.

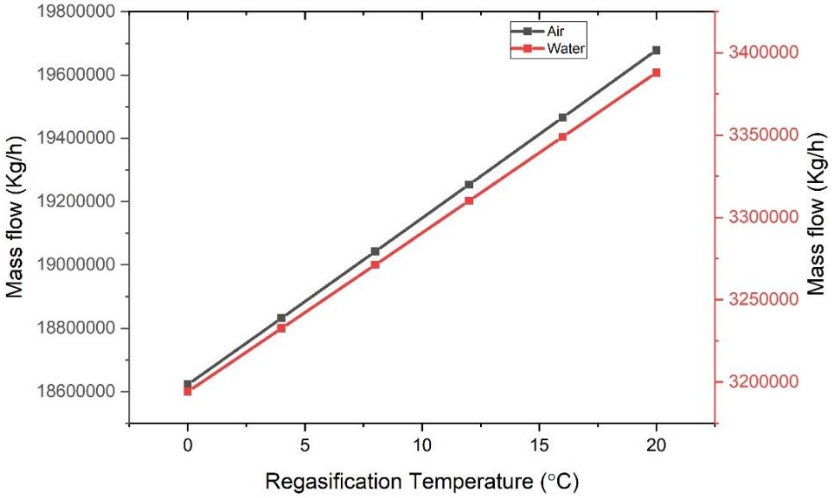


Figure 30-LNG re-gasification Temperature vs air and water mass flowrate

This graph a plot of relative air and sea water mass flow demonstrates, how air mass flowrate is comparatively more due to lower heat transfer coefficient and heat capacities in a system [73][74].

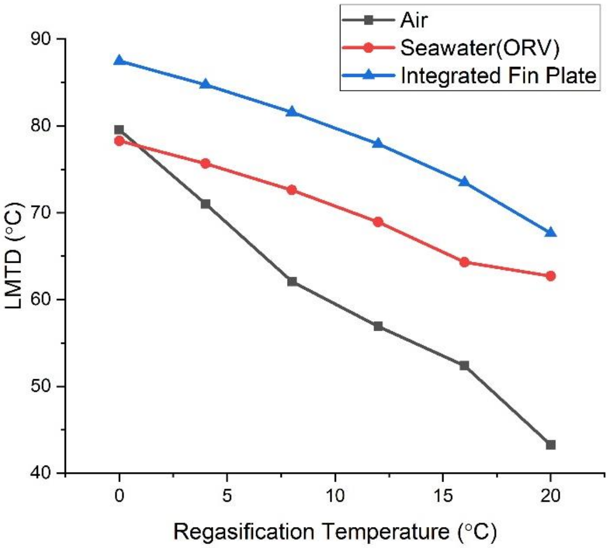


Figure 31-Regasification Temperature vs LMTD of natural Alternatives

As this comparative graph indicates a cycle of relative LMTD Drop for a range of output LNG re-gasification temperature indicating how the LMTD dropped with the likely increase in output temperature. The most significant of the drop was that of air due to low heat capacity compared to other alternatives.

4.4 Integrated Series Water and Air system

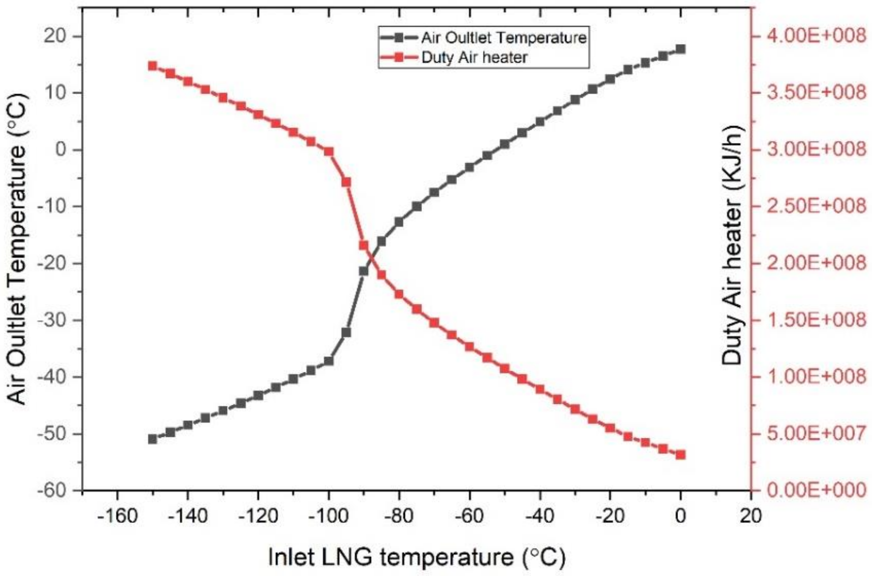


Figure 32-Input LNG Temperature to Air Heater vs Duty and Air Output Temperature

This system in series, the likely increase in the flow rate reportedly increase the overall temperature of air at output exceeding the necessary range of absorption. All this will cloud into a frost, freezing, temperature shock on equipment coupled with the crystallization of water vapors in air. So, the temperature distribution in this system should manifest into optimal ranges which in this case amounts to system having equilibrium duties and temperature ranges [75].

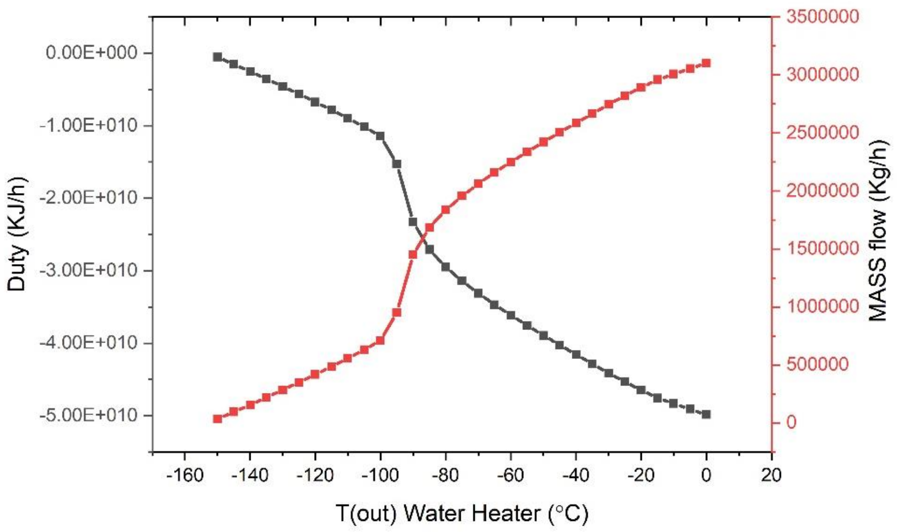


Figure 33-Water Heating Temperature Vs Required Mass Flow and Duty

Moreover, the water system behavior is similar to the air system but the likely heat capacity and heat transfer coefficient's lead to likely transitions in behaviors.so the cumulative effect of system in series using optimal ranges increases the overall heat transfers and vaporization [54].

4.5 Intermediate fluid Vaporizer

4.5.1 Glycol-Seawater System

This system in conjunction with sea water utilizes glycol an excellent coolant to transfer the heat at sub-zero level. The closed loop circulation of Glycol alters the inherent weakness of process like freezing of ice causing fouling and other. Here the graphs will demonstrate how the water atmospheric variability pushes the dynamics of process.

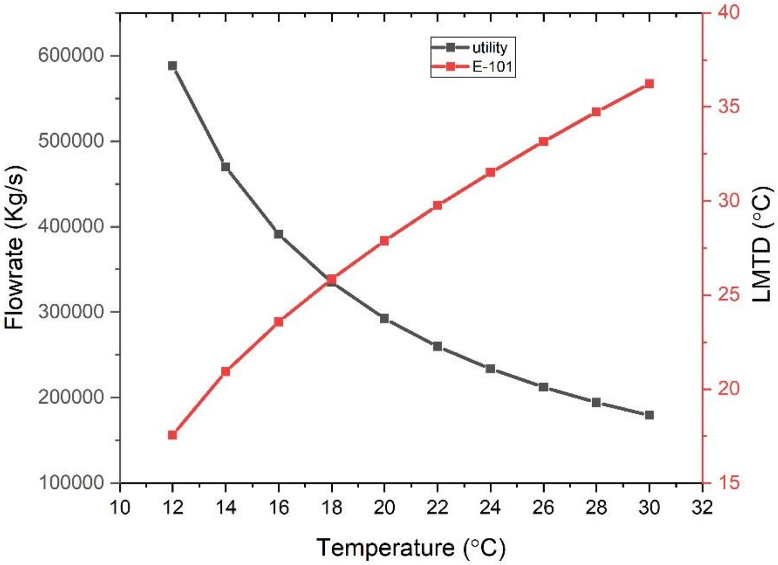


Figure 34-Seawater Temperature Variability vs the Required Flowrate and Vaporizer LMTD

The sea water temperature variates around the year, which will resultantly impact the performance of Vaporizer. In order so to maintain the required push for gasification, the required heat will be supplied by increasing the flowrate of seawater. This steep rise of flowrate with decreasing water temperature and decreasing LMTD value, the mean driving force behind heat transfer laws. However, this setup is least impacted compared to ambient air and seawater unit due to utilizing an intermediate heating medium distributing heat. Thus, causing little of freezing and performance losses in heater [63].

4.5.2 Glycol-air cooled

This system analogous to the previous version of glycol water uses another heating sources heating medium ambient air heating. The air temperature variability will alter the dynamics and overall characteristics of system. Thence, output air temperature a vital factor in this consideration is studied with the relative. The graph in figure-36 is illustrative of how gasification temperature impacts the performance by either pushing the output air temperature into critical zone leading to a higher ice buildup [76].

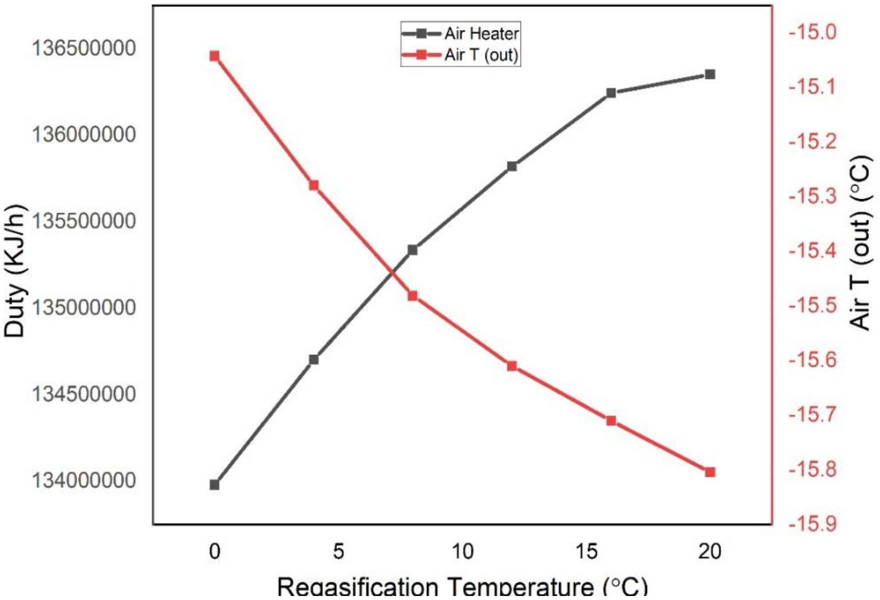


Figure 35-Regasification Temperature vs Vaporizer Duty and Air Output Temperature

This buildup of ice decreases performance of vaporizer may even lead to failures and ice. subsequently, the lower temperature of ice further crystallizes the moisture in air leading to fog and low visibility.

4.5.3 Propane-seawater System

This system another analogous process utilizing a wide array of parameter and principally the difference in the intermediate coolant or medium of heat exchange.

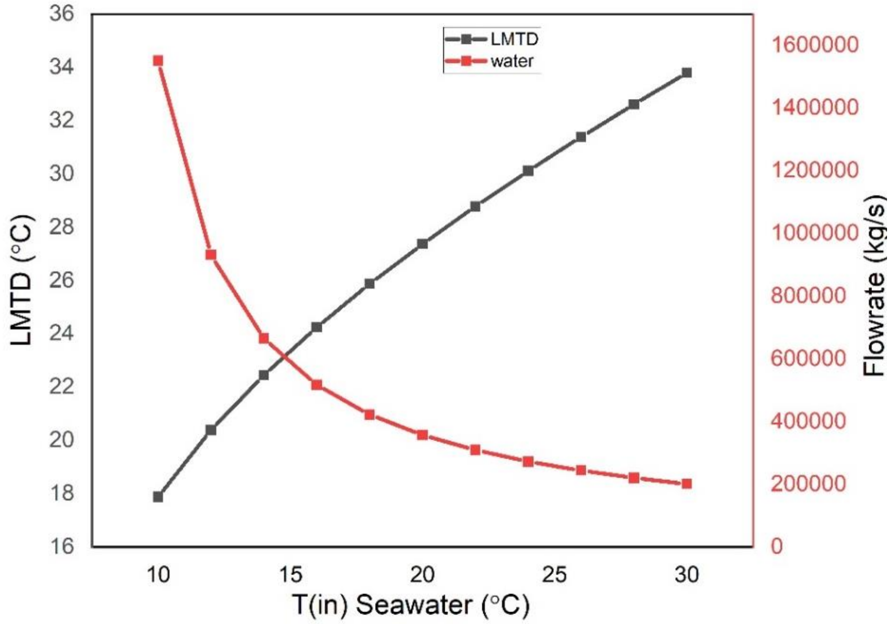


Figure 36-Annual Seawater Temperature profile vs Vaporizer LMTD AND Required Flow rate

This steep curve of propane refrigerant is due to more volatility and lower heat transfer performance and rapid change of properties with temperature. All of this increased flow rate with decreasing sea-water temperature is substantiation of previous phenomena and heat transfer laws [59].

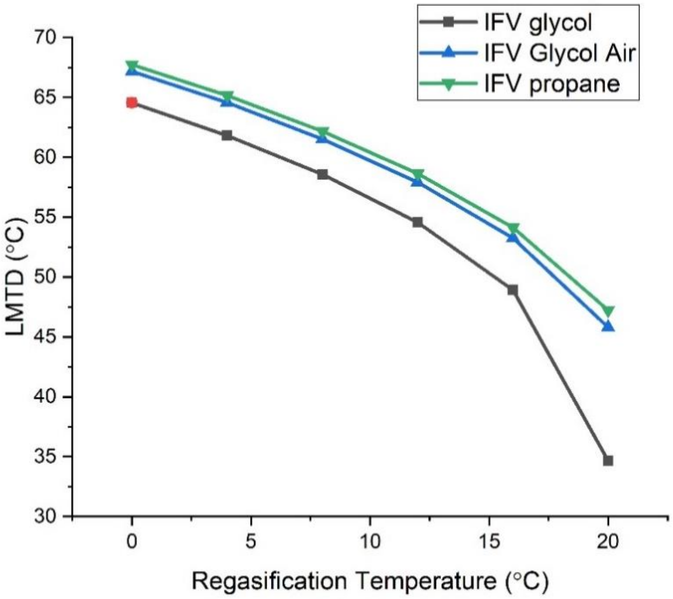


Figure 37-LNG regasification Temperature vs Relative LMTD Profile of IFV alternatives

This figure-37 is an illustration of relative performance by the three IFV alternatives. LMTD, the driving force behind the heat transfer is demonstrating the relative passage of vaporization. The high propane trend is due to temperature-phase equilibria of propane requiring a lower Working temperature compared to the most robust glycol-water system [57]. This glycol-water system is highly stable and has broad operating range compared to propane as intermediate due to the fluid property characteristics.

4.6 Fired Heating Systems

4.6.1 Direct Fired Heating

The direct heating System directly heats a highly combustible material employing a minute fraction of LNG re-gasified in the process. The subtle fuel air ratio and their relative flowrates are instrumental in determining the output temperature of re-gasified gas [76].

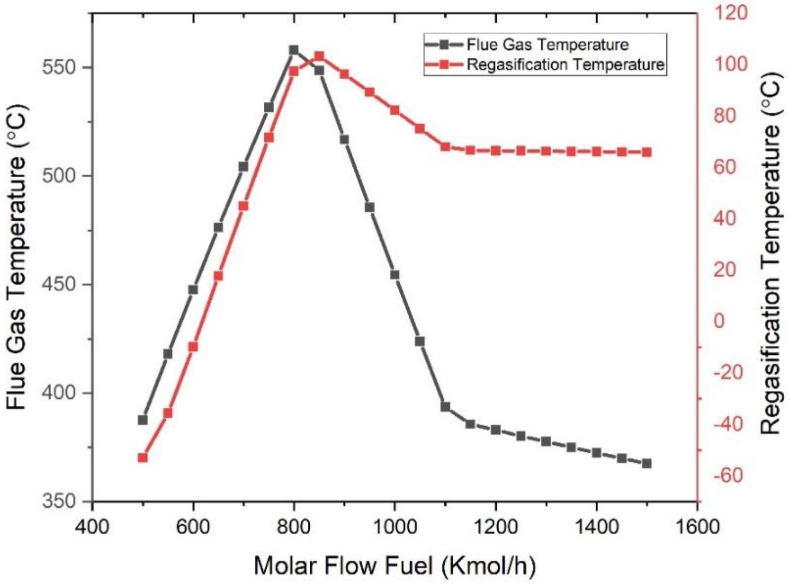


Figure 38-Rate of Fuel vs the output and exhaust temperature

37 – demonstrates how the increase in the fuel rate increases the temperature at output to a point where the oxygen lack stabilizes the output temperature but steeply decreases the exhaust gases temperature. Thus, the peak point is the optimum fuel rate to efficiently re-gasify at this feed rate of 500MMSCFD.

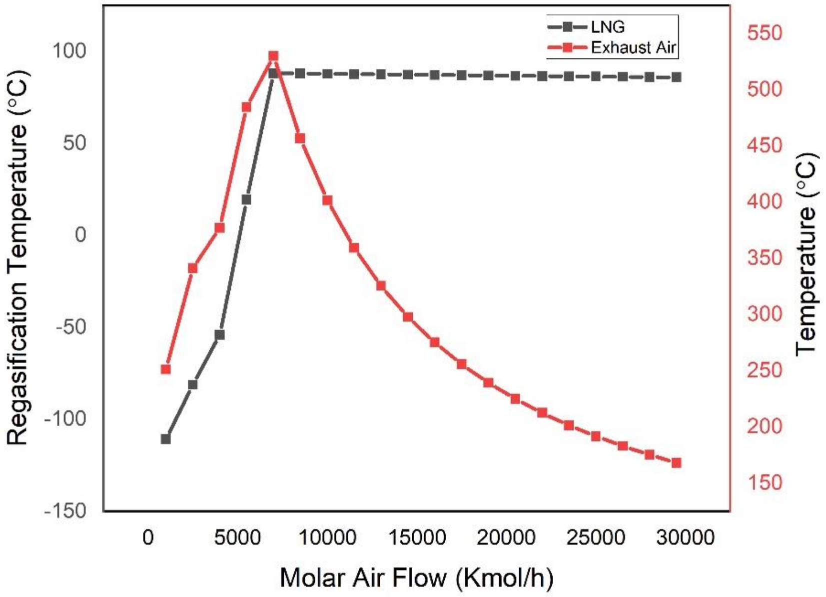


Figure 39-Rate of Air Flow vs the output and Exhaust temperature

Subsequently, the air flow rate being the limiting agent to any combustion reaction is pivotal to determining the heat transfer and efficient combustion in process.as the figure -36 represents this relation demonstrating how the air combustion process has a peak point representing the efficient combination of air flow rate required [76]. Beyond which there is a steep drop in temperature of output and exhaust gases. This is a manifestation of diluting of the heat content in clear cognizance of burning principle.,

4.7 Waste Heat Recovery

This process is an integration of wide adaptability and utilizing the waste resources from a power plant or any other industrial process. The flue gases entering leaves at a temperature of feeble range of high 170˚C. This graph illustrates how an increasing temperature allows for more flow rate or a more drop in output flue gas temperature. This illustration is in contemplation of heat transfer law and motion [67].

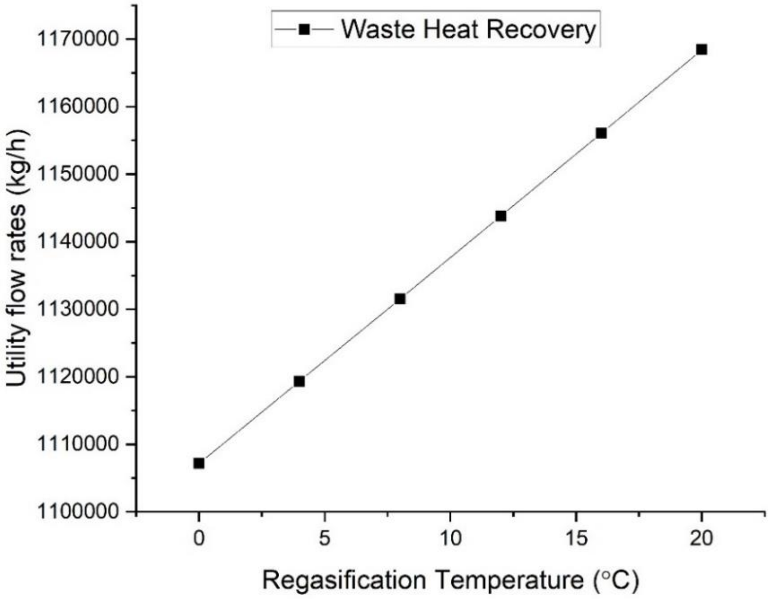


Figure 40-LNG regasification Temperature vs required mass flow rate of waste flue gases

The Heat Transfer for a different parametric temperature requires a higher utilization of duty, which will automatically augment into increasing mass flow rate as demonstrated by figure 40. more of flue gases from an integrated power plant or industry will be required for a desired change in output and fixed temperature change of flue gases. Flue Gases for a particular temperature change range are highly efficient but beyond these ranges the pressure drops, scaling, deposition compound the problems detrimental to maintenance and operation of process [77].

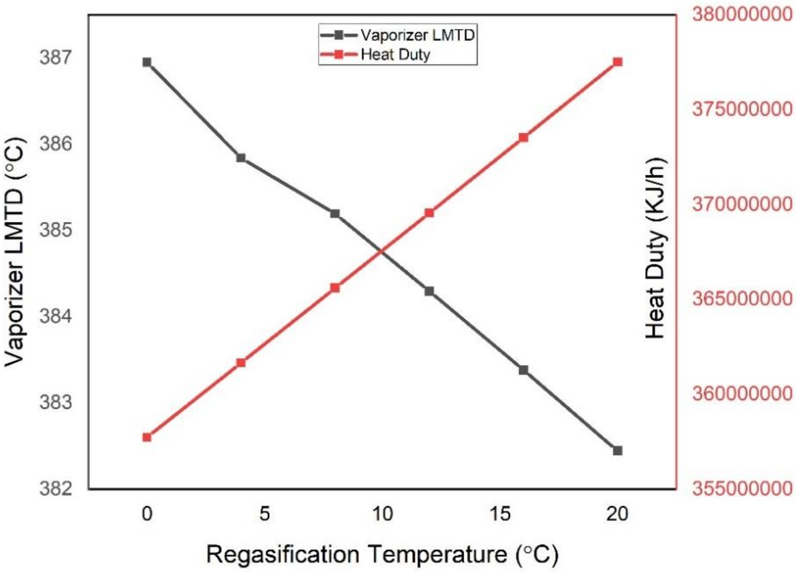


Figure 41-Outlet Temperature vs LMTD and Heat duty of Vaporizer

Obeying heat transfer law, the necessary phase change of system employing WHR vaporizer conjoins the increasing duty and LMTD for a required increasing outlet Temperature for a vaporizer. The Phase change implicated in the sudden change in LMTD is a manifestation of changing Phase and subsequently heat transfer change. This is due to properties of vapor being less propounding than other [78].

4.8 Utility Systems

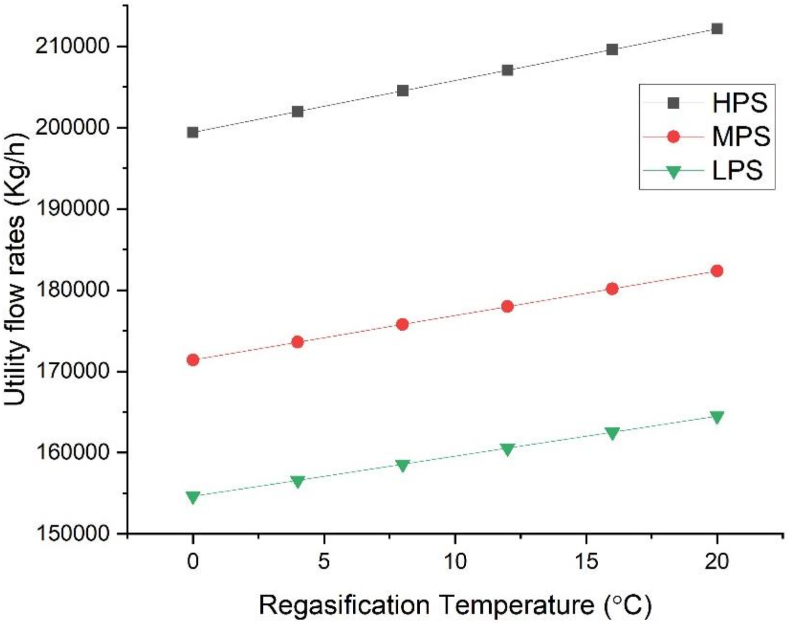


Figure 42-LNG regasification Temperature vs Relative utility flow rate

The figure 42- profile is illustrative of mass flow required for regasification of LNG while encountering for a mere 1˚C drop in utility temperature. As of HPS dropped from 275 to 274˚C, the higher mass required indicate a low Vapor heat transfer coefficient, while MPS and LPS also saw either drop from 175 to 174 ˚C or 100 to 99˚C. the highest mass flow rate of HPS is a manifestation of high temperature of steam but a small drop.

4.9 Comparative cost and Operational Parameter Analysis

The cost and operational parameters are a vital consideration to decisionmaking.in order so the requisite motivation for a process is easy maintenance, cost and reducing the energy consumption, making the process environmental friendly.in this pursuit, we have to optimize and compare them relatively. For this understanding, duty is an essential component to mark them, as this process employing a sundry of utilities. All of these variations plotted on a graph is demonstrated below.

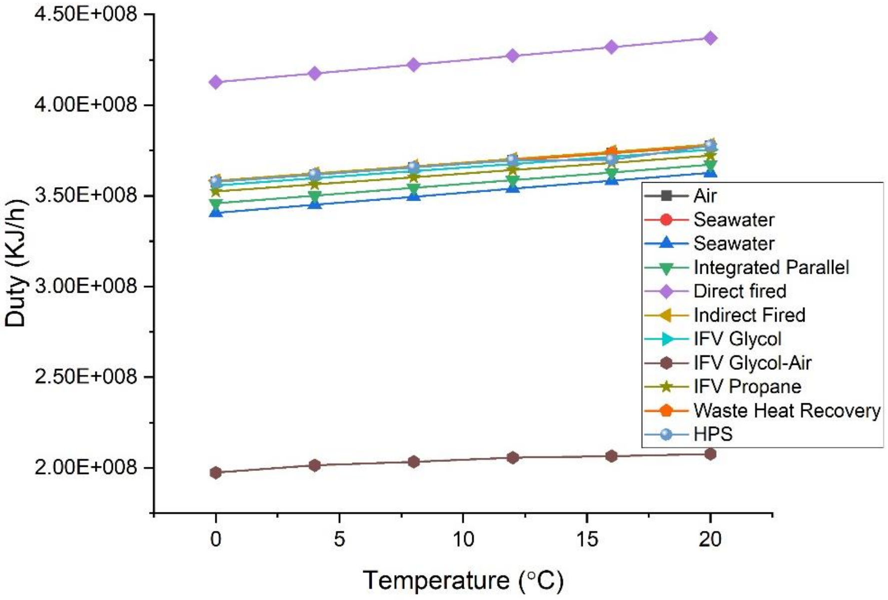


Figure 43-LNG regasification Temperature vs Relative Duties of Alternatives

In the figure 43, The process anomaly is the waste heat recovery lying on the top, with a wide divergence on top. all this is due to a higher heat component of waste heat gas plus a high temperature differential between both streams [20]. Moreover, IFV glycol air marking a variation from another similar Process demonstrates the custom construction can highly decrease the duties, even in the demanding ambient air heating. This tool of duty is highly cognizant of environmental significance. Apart from this consideration, the capital cost at the start of process demonstrates the equipment and installation cost for regasification. All these alternatives Capital Costs are plotted on a scale. The IFV's along with SCV demonstrates a relatively higher cost in comparison to other constructions for gasification of LNG. For instance, a higher heat surface area is also phenomenal in increasing cost. At the lower end, the waste heat recovery with the lowest capital cost is due to little and simple equipment requirements [79].

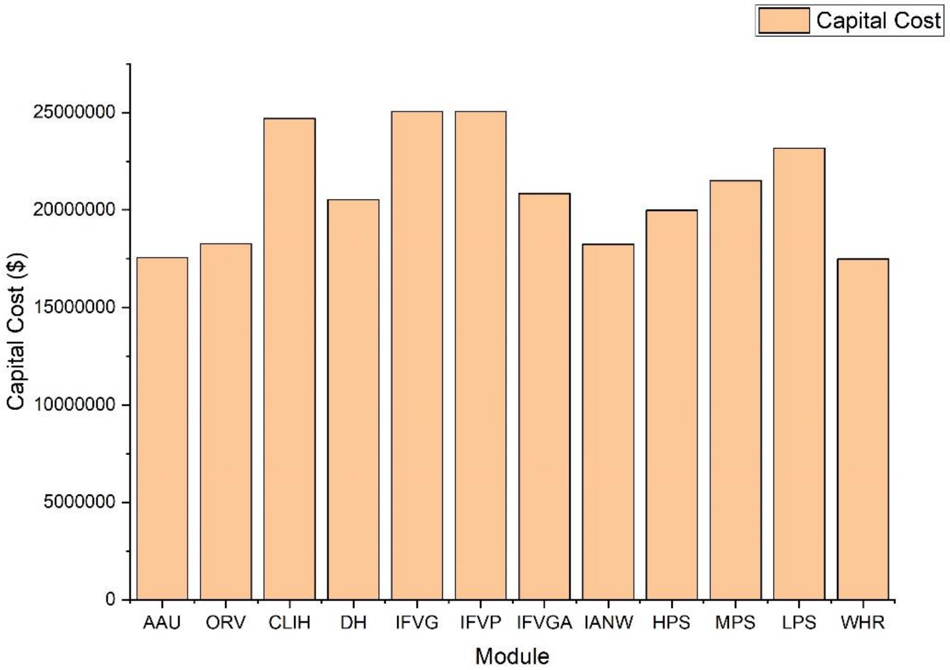


Figure 44-Capital cost Estimates of LNG Re-gasification Alternatives

The relative plot of operating cost is highly varied from every alternative to another this is a deciding factor and instrumental to economic stimulus. The closed loop indirect heating similar to submersible combustion vaporizer with a costly utility of natural gas and subsequent construction employing various pumps exchanger and closed loop installation makes it most expensive operating and associated maintenance costs. Simultaneously, the ambient Air Unit (AAU) AND IFVP, with the lowest cost resounds the technical and financial viability of the process [78].

In the figure-45 the graph is representing alternative operating cost for range of different RLNG operation alternatives. The closed Loop indirect heating or SCV with the highest operating and capital cost is a sustainable alternative due to range of parameter like simple construction and easy maintenance operation. But for the better, it is replaced by recent innovative low operating and capital alternative options like IFVs. While, in opposite the AAU and ORV are being widely employed in process industry due to low-cost operation and capital, however their maintenance and life is costly. Also, the utility system Heating system are fuel dependent [26].

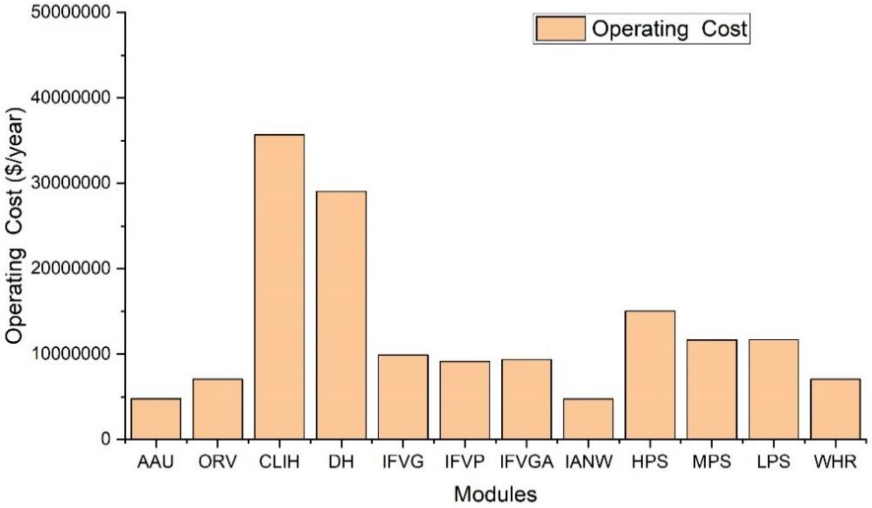


Figure 45-Relative Operating Cost of Alternatives

4.10 Analysis

As mentioned previously the process selection criteria involving multifaceted parameter involving cost, safety, environment, Rate of return, Maintenance and others. Among these alternatives the direct Combustion process being highly insecure due to heating and expansion of highly inflammable liquid by combustion reaction, thus the degree of freedom involved in choosing is extremely limited and risky.

Since the high-Cost alternatives like CLIH (SCV) cost dearly and impose an environment constraint upon selection due to burning of fuel for heating. However, this is accommodated by cheaper maintenance cost and life of plant. Indirectly, one factor is being accommodated at the expense of other [44].

Similarly, the AAU, ORV AND Integrated Heating System employing the water or air are least expensive operating but the maintenance, life of plants and environmental constraint like temperature variability of Pakistan inflict decision-making. This intransigence accounts for higher scrutiny and evaluation of alternative depending upon the local conditions [36].

Table 2-Comparative Analysis of Alternatives

Alternatives	**Operating cost and Capital Cost**	**Durability**	**Energy**	**Safety**	**Sustainability**
AAU	Low	Low (deposition and maintenance)	Low	Mild	Climate Variability
ORV	Low	Low (deposition and maintenance)	Low	Mild	Climate Variability
ISWA	Low	Low	Low	Less prone	Little Variability toward climate
IPWA	Low	Low	Low	Less prone	Little Variability toward climate
SCV	High	High	High	Safety record	No-green alternative
Fired Heating	Highest	High	High	Many Hazards	No-green alternative
Waste Heat Recovery	Low	High	Low	Susceptible	Environmentally safe and green
IFVGA	Low costs	High	Low	High	High
IFVP	Low costs	mild	Low	Mild	High

IFVG	Low costs	High	Low	High	High
Steam Utilities (LPS, MPS, HPS)	High Costs	---	High	---	---

The Waste Heating Recovery systems are trending and fad of modern LNG focused research. This module with a relatively lower operating and capital cost is being treated in conjunction with industry.

Utility System are widely used in process Industry for Heating Process. Initially the utility costs and required apparatus are inflicting a cost dominating the selection. Furthermore, like previous use fuel or energy foe creation of steam involving negative environmental externalities cost. The robustness of regasification plant and little space requirement greatly reduces the process mapping [46].

Lastly, the Intermediate Fluid Vaporizer are sundry system employing the natural Heating system and the use of intermediary heating fluid. The use of heating system greatly reduces the overall pressure upon the maintenance cost and inherent weakness allowing for freezing and fouling of system walls. Furthermore, the overall Heating System is greatly enhanced employing a wide array of parameter and broad operation. For instance, the IFV can even work with Seawater temperature of 1℃ [57].

Conclusion

Natural gas as the major source of energy is imported from offshore sources in the form of cryogenic liquid, in need of gasification. As this liquefaction is a highly energy intensive process, so various schemes and model alternative exists to re-gasify it in an environmentally and economically sound manner [80]. In the end, the relatively subtle choice to make in selection of process citing the environmental and economic feasibility [81]. The heat utility, mode of heat transfer, structural configurations employed in gasification of LNG, under the domestic factors and variables of Pakistan.

As this study was focused mainly upon utilizing the environmental utilities to describe a relatively cheaper operating and capital costs of process. For this process, the Ambient air unit along with seawater utilizes the environmental capital and least energy dependent process outlying any natural capital [82]. However, the structural consideration imposes a cost upon the process, with further call for higher maintenance and tolerance of the system. due to the fact that, the frosting, fouling and other depositions along with temperature shocks triggering structural and process anomalies [83].so the consideration of establishing a primary base envisions to expands the horizon for relatively subtle choices [84].

Moreover, the IFV systems are a necessary addition to the existing range of vaporizers. The composure as for the intermediate is primarily dominated by the glycol, propane or other relatively low boiling refrigerants acting as heat transfer medium to compliment the necessary shock. Since, the intermediate usage narrowed the temperature ranges, preventing any shock to the process causing failures to the safety and stability of process. Since operating cost of this alternatives are comparatively lower along with the little maintenance cost required [14].further , the high operational reliability compliment the needs for further safety and process. The IFV heating stands out against all the odd due to lower cost, operating condition and lower environmental footprints

Since, the contemporary regasification processes involved continue to use natural gas burning to heat and re-gasify the LNG. As this carbon sensitivity and cost of fuel makes the operating cost high and unwanted in terms of environmental concerns. Moreover, the concerns of safety are of importance to feasibility due to nature of process and materials involved [85].

As for the utility system employing the three different types of utilities requires extra equipment’s and installation, which restricts it usage in compact offshore plants. This limitation of space coupled with high cost associated are factor inhibiting the utilization of common heating medium [46]. Since the heating requirements are also low, which can be extracted from natural process and extraction of cold.

The waste heat recovery process utilizes flue gases from existing plant in shell and tube compact structure. Moreover, the high LMTD make rapid heat transfer but the sudden expansions can account for failure compounding the problems in process [50]. The low cost along with optimizing the efficiency and performance of powerplants are an additional benefit. However, the higher maintenance cost due to deposition of particulate matter are also influencing the process efficiencies [86].

In addition to all these, the likely impacts of environment factor were also demonstrated. for the first, the likely output LNG regasification temperature impacted the output condition establishing a limit of it. Beyond which the process anomalies like the frosting occurred inhibiting heat transfer and establishing fog in air.

Simultaneously, the winter temperature greatly reduced the activity and heat transfer limiting the consideration for structure and output condition. Hence, this dire scenario can lead to systematic failures, leading to disruption in power and utilities. Apart from these AAU and ORV, the modified structures like integrated series in the form of cooling tower is vital allow to versatility and robustness compared to simple air and water system.

The IFV systems in comparison are prominent in performance due to little heat requirement and utility. Furthermore, the environmental soundness establishes the clear choice [16]. Also, IFV behavior and graphs demonstrated how the profiles changed in mass flowrate, duty and LMTD. These trends indicate the validity of Newton law of cooling and Fourier’s law of heat conduction.

So, the correlation was established plotting temperature change and utilities flow rate behavior upon the outlet LNG characteristics and temperature variability. Apart from these, LMTD a driving force to reckon with also demonstrated how the system behaved in reaction to change in stimulus. Lastly, the comparative duties, operating cost and capital costs of all those alternatives. All these demonstrated the likely choice to make in the backdrop of local conditions of Pakistan.

So, the purpose here was to intercept the likely optimal parameters and range for efficient and productive working of the LNG plants. In this the most efficient Re-gasification Temperature came out to be 4˚C. also the most feasible alternative after a range of evaluation came out to be the IFV, due to the range of consideration dictating the final selection [63].

As all these influencing factors are result of rigorous research and modelling of the LNG regasification cycle reflecting the real-time factors and consideration. Thus, these results help established the feasibility of various available alternatives.

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