STM JOURNALS

Journal of
Offshore Structure and Technology

ISSN: 2349-8986
Volume 8, Issue 2, 2021
DOI (Journal): 10.37591/JoOST

http://techjournals.stmjournals.in/index.php/JoOST/index

Research JoOST

Proposal of System for High Efficiency Energy Extraction from LNG and Study of Use of EGR and SCR System in Ships

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Abstract

The paper focuses on the green shipping methodologies and environment friendly practices. Liquefied natural gas (LNG) is one of the most effective alternatives to traditional shipping fuels. Ports have LNG re-gasification systems, which generally use Open Rack Vaporizers (ORVs) to convert the LNG to NG. In this process, a lot of the 'cold energy' is lost. A proposal for a LNG re-gasification system has been made in this paper which can be installed both on-board a ship or in a port and will successfully utilize the cold energy of LNG. In addition, analysis of the experimentation of inert hydrogen gas used in cooling exhaust gas recirculation (EGR) systems on-board ships to stop the production of NOx at peak temperatures in the engine chamber has been done. The uses of various catalysts on selective catalytic reduction (SCR) systems to curb NOx production and data analysis on NOx reduction after treatment have been studied. Germane and pertinent observations were taken for the following procedures.

Keywords: High efficiency, energy extraction, selective catalytic reduction (SCR), exhaust gas recirculation (EGR), liquefied natural gas (LNG)

INTRODUCTION

From the earliest times, ships had to be fueled with something. What started with rowing evolved to using wind-in-sails and then came mechanical automation! Engines in ships changed the world, created an entire industrial sector and the maritime sector continues to be the only most globalized field in the world. Here is what we need to keep in mind. Thousands of gallons of heavy diesel oil are burnt to empower the engine. The carbon footprint of such usage is beyond critical and the Sulphur produced is beyond contagious. As per IMO rules, ships have been trying to use refined diesel and scrubbers but maintenance and installation of such mechanisms fetch hefty prices for the owner company. This is exactly where natural gas comes into play. LNG maintains its liquid state at -162°C under atmospheric pressure. This form of LNG is mostly preferred because maintaining temperature conditions is easier and cheaper compared to maintaining pressure. NG ignites at 1100°C compared to diesel vapor at 60°C. In addition, the amount of energy is much higher than diesel fuel when efficient engines are used (diesel gives 41–46 kJ/kg compared to 45–55 kJ/kg of LNG). The only problem arises in the conversion of LNG to NG. Putting up a separate boiler for just heating the LNG with steam and cooling the steam again to form water is highly inefficient. Instead, what is done is the usage of an ORV (Open Rack Vaporizer). The ORV system is simple and

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Received Date: July 10, 2021
Accepted Date: August 01, 2021
Published Date: August 25, 2021

Citation: Bh. Nagesh, Tamoghno Banerjee, Aby Joseph, Anagha S., Samborta Gongopadhyay. Proposal of System for High Efficiency Energy Extraction from LNG and Study of use of EGR and SCR System in Ships. Journal of Offshore Structure and Technology. 2021; 8(2): 36–48p.

effective. A heavy-duty pump is used to pump in seawater. LNG is passed through the several rack pipes and the seawater moves in simple circles around these pipes. (High conductivity metals are chosen to build the racks for exchanging heat. Generally, copper should be avoided; instead, Nickel alloys serve the purpose properly). Compared to the temperature of LNG, seawater does a pretty good job of vaporizing the gas due to its high heat transfer coefficient. Carbon and NOx emissions are a straight 50% less in LNG compared to those in diesel, while particulate emissions are 10 times lower in LNG than diesel. Clubbed with low energy scrubbers and exhaust gas recirculation methods, LNG emissions can be purified. Using ORV to vaporize the LNG is efficient up to 43% because the entire cold energy of LNG is wasted in this method. Research and ideas are being brought up in this area of study. A Rankine cycle including several shell and tube exchangers or plate exchangers can be used to extract the cold energy of LNG, and a utilization factor of 0.43 (or 43% efficient) would also be very useful.

PROPOSAL FOR HIGH-EFFICIENCY ENERGY GENERATION SYSTEM FROM LNG

Natural Gas is recovered in gaseous form and for transportation purposes, it is liquefied. Liquefaction conditions include 1 atm pressure (normal atmospheric pressure) and -162°C. This amounts to something around 900 kJ/kg. While re-gasification, 830–860 kJ/kg of this cold energy is lost (Figure 1(a)).

The proposed system will be using a boiler, one turbine of minimum 85% efficiency, a main water pump, an optional use heat pump (condenser) for the primary steam cycle. Remaining cycles will be a Freon cycle and a LNG supply and output cycle. The Freon cycle will consist of freons like R134a and R23b, which will be pumped against a tube of LNG to facilitate heat exchange. The Freon cycle will aim to absorb heat from the steam and gradually supply heat to the LNG as it passes through several LNG/H_2O condensers. These condensers are all shell and tube type heat exchangers or plate and shell type exchangers. The LNG will be heated gradually over a length and the cold energy of the LNG will be used to bring down the temperature and condense the steam, so that the heat pump work is reduced as far as possible [1].

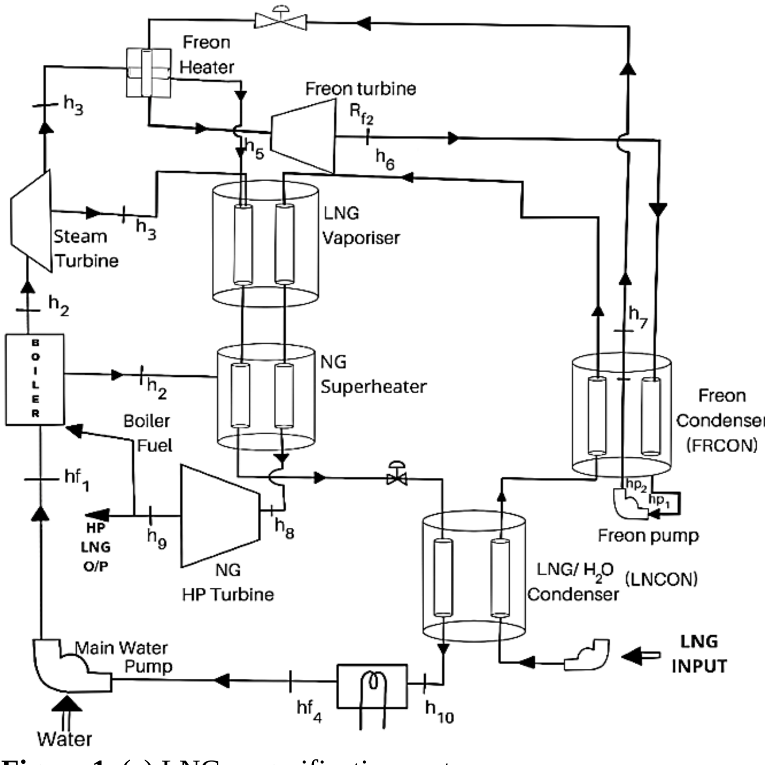

Figure 1. (a) LNG re-gasification system.

MATHEMATICAL CONSTRAINTS AND ASSUMPTIONS

The turbine and boiler of the steam system must be chosen according to the following requirements:

- Pressure handling up to 25 MPa.
- Temperatures up to 1000°C.
- Stopper locks of up to 5 MPa tolerance.

The above model is software-tested to work at steam-turbine inlet pressure of 14.992 MPa at 482.22°C with outlet properties as follows.

- Outlet Pressure: 13.789 MPa (to be re-distributed with multiple pipes to reduce pressure and thermal loading)
- Outlet Temperature: 398.389°C
- Specific Enthalpy: 2998.679 kJ/kg
- Specific Entropy: 5945.2559 kJ/kg/K
- Assumption:
  a. Inlet and outlet flow are same at 16.5 tonnes/hour.
  b. Heat duty calculated using standard formula * 1.25
  c. Turbine is 80% efficient.

Material to be used for piping is very critical.

EVALUATION OF PROPERTIES UNDER DIFFERENT CONDITIONS

Effect of Reduction in Outlet Steam Temperature of Ng Hp Turbine and Steam Turbine

Generally, an outlet steam temperature study is conducted to find the efficiency of the entire system and find the estimates on how much fuel is to be consumed per unit of time as per requirement. A typical system consists of outlet temperatures like 399°C with superheated steam at inlet pressures of 15 MPa, which is a suitable value to effectively run a system at low risks [2]. Keeping the pressure constant, when temperatures of 260°C are put as outlet temperature, there is a sharp fall in system enthalpy, 1134.1576 kJ/kg that keeps on increasing at a decreasing rate until 315.5556°C where the enthalpy is 1434.9094 kJ/kg. When temperature is raised by 1°C, a drastic increase in seen in specific enthalpy. In Graph 1 below, the steep up rise of the curve represents a sudden increase in energy of the system. This in turn represents that below 316°C (at that specific pressure) condensation occurs in the turbine (Table 1 and Figure 1(b)).

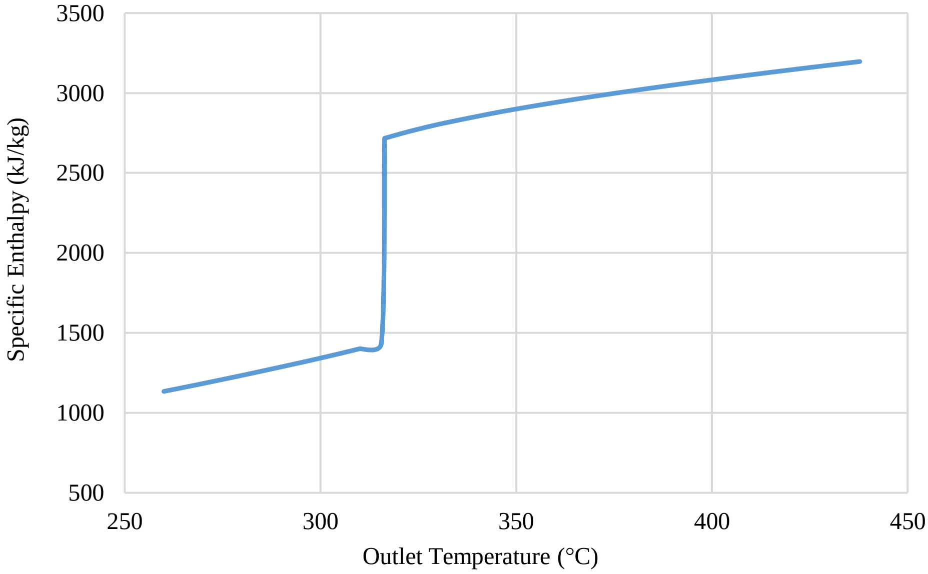

Figure 1. (b) Outlet temperature versus specific enthalpy.

Table 1. Outlet temperature versus specific enthalpy.

Pressure (MPa)	Temperature (°C)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg-K)	Specific volume (m^3/kg)
10.58	260	1134.1576	2.868	0.0012
10.58	265.5556	1161.3718	2.9182	0.0012
10.58	271.1111	1189.0512	2.9726	0.0013
10.58	276.6667	1217.4284	3.0229	0.0013
10.58	282.2222	1246.0382	3.0731	0.0013
10.58	293.3333	1305.3512	3.182	0.0014
10.58	298.8889	1336.0544	3.2364	0.0014
10.58	304.4444	1367.688	3.2908	0.0014
10.58	310	1400.7172	3.3453	0.0014
10.58	315.5556	1434.9094	3.4039	0.0015
10.58	316.3889	2716.5354	5.581	0.0167
10.58	316.5556	2717.6984	5.581	0.0167
10.58	321.1111	2749.5646	5.6354	0.0174
10.58	326.6667	2783.9894	5.694	0.018
10.58	332.2222	2814.9252	5.7443	0.0187
10.58	343.3333	2869.8188	5.8364	0.0199
10.58	348.8889	2894.9396	5.8741	0.0204
10.58	354.4444	2918.4322	5.9118	0.0209
10.58	360	2940.9944	5.9494	0.0214

Table 2. Inlet temperature versus specific enthalpy.

Pressure (MPa)	Temperature (°C)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg-K)	Specific volume (m^3/kg)
24.1317	371.1111	1812.4192	3.9775	0.0019
24.1317	376.6667	1895.69	4.1073	0.0021
24.1317	382.2222	2155.039	4.505	0.0032
24.1317	387.7778	2429.507	4.9237	0.005
24.1317	393.3333	2537.4334	5.087	0.0059
24.1317	393.8889	2545.807	5.0995	0.0059
24.1317	394.4444	2553.948	5.1079	0.006
24.1317	395	2561.8564	5.1205	0.0061
24.1317	396.6667	2584.186	5.154	0.0062
24.1317	397.2222	2591.3966	5.1665	0.0063
24.1317	398.3333	2605.12	5.1874	0.0064
24.1317	398.8889	2611.6328	5.1958	0.0064
24.1317	399.4444	2618.1456	5.2042	0.0065
24.1317	400	2624.4258	5.2168	0.0066
24.1317	401.6667	2642.5686	5.2419	0.0067
24.1317	404.4444	2670.7132	5.2837	0.0069
24.1317	410	2720.9548	5.3591	0.0074

Effect of Reduction in Inlet Steam Temperature of Ng Hp Turbine and Steam Turbine

Inlet steam temperatures should be in correspondence with the efficiency of the steam turbine taken [3]. Lower limit should be chosen so that the power output is satisfactory as well as yields an output temperature of greater than critical limit. At the test pressure of 24 MPa, there is a significant increase in the enthalpy when temperatures increase within the range of 300–400°C. At 371°C, 382°C the enthalpies are 1812.4192 kJ/kg and 2155.039 kJ/kg, respectively (Table 2 and Figure 1(c) and Figure 2).

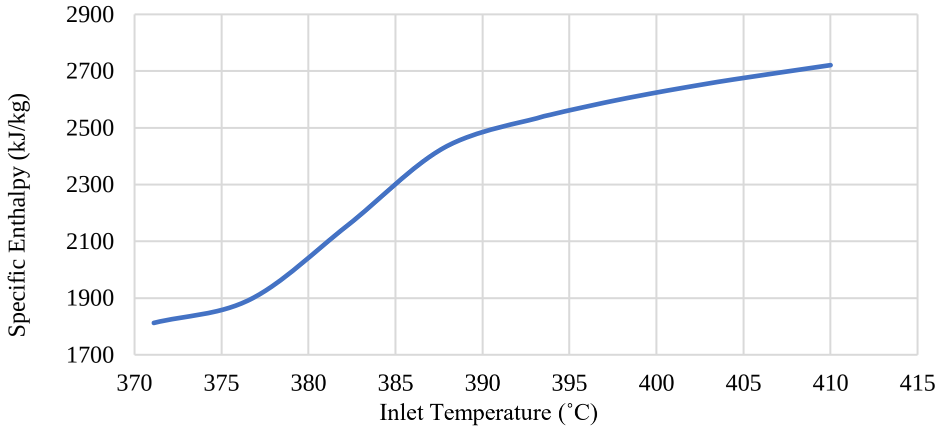

Figure 1. (c) Outlet temperature versus specific enthalpy.

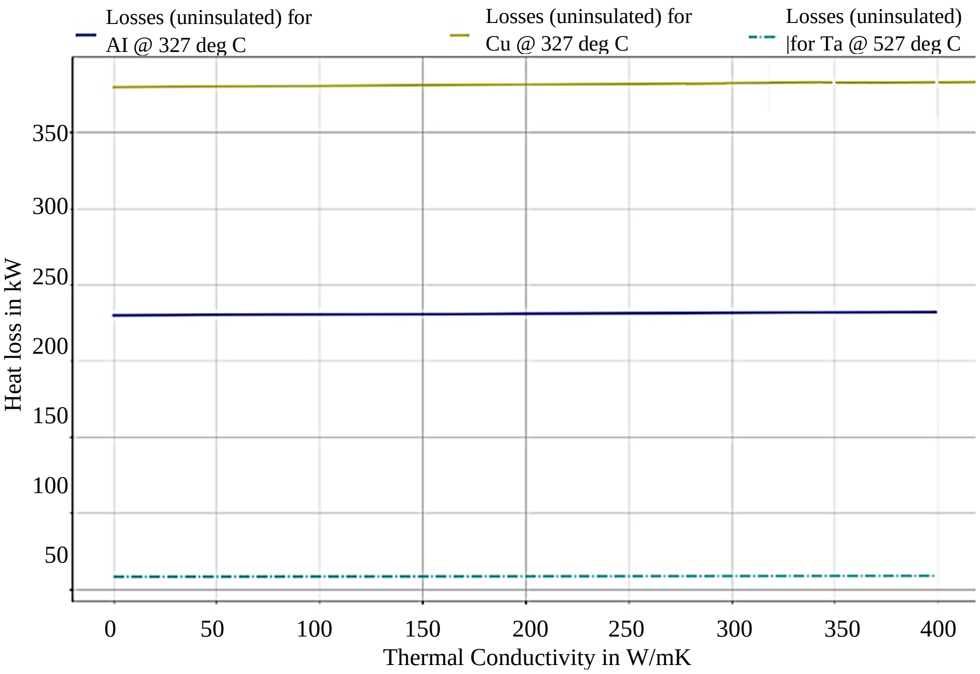

Figure 2. Heat losses comparison.

DEPENDENCE OF SYSTEM EFFICIENCY ON PIPING MATERIAL

Piping should be chosen with valves (preferably Gate valves to reduce turbulence) wherever necessary. Material used for pipes is suggested to be an alloy containing Tantalum and Tungsten [4].

Even aluminium and copper have shown high temperature resistance capabilities. Other materials like carbon-nickel alloys would have been a perfect material if the temperatures of flow were lower. Here are a few heat loss curves for uninsulated Al, Cu, Ta at different temperatures (Figure 2).

Heat Losses Associated with Pipe Thickness (In Terms of Radius Ratio)

The radius ratio is the ratio of the outer radius to the inner radius of the pipe. Here it is being assumed that the pipes are uninsulated. It is seen that conduction losses are dominating over convective or radiation losses in uninsulated non-alloy pipes. Mathematical calculations are started at a ratio slightly greater than unity. At $r_O/r_i = 1.005$, Al (127°C) shows heat losses of 1.541×10^8 W, Al (527°C) shows 7.452×10^7 W and Tantalum (727°C) shows 1.908×10^7 W losses. Moving further down at $r_O/r_i = 1.5012$ Al (127°C) shows heat losses of 1.892×10^6 W, Al (527°C) shows 9.1487×10^5 W and Tantalum (727°C) shows 2.342×10^5 W losses. This pattern is further followed till radius ratio of 2. The following patterns are seen in Figure 3.

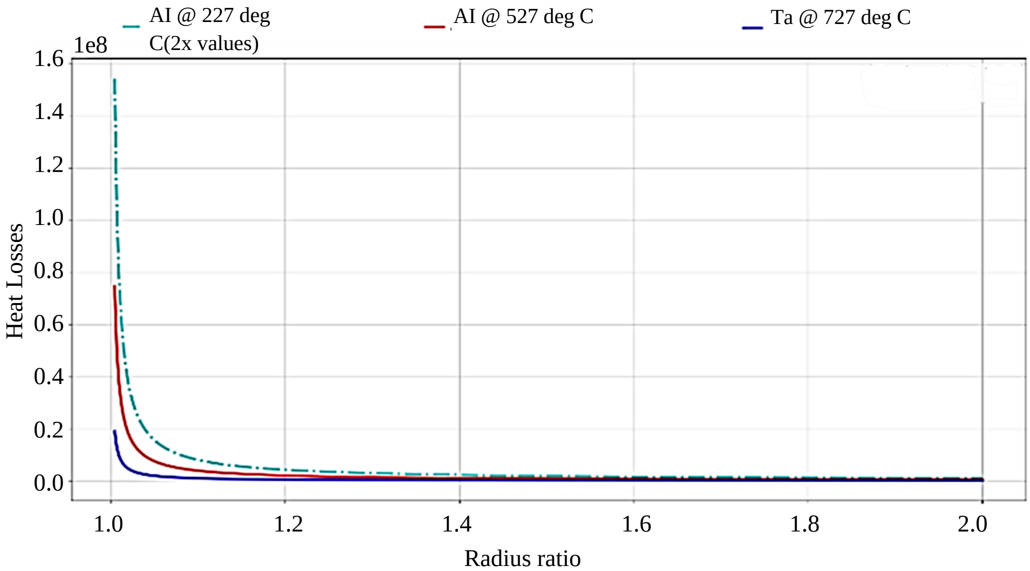

Figure 3. Dependency on radius ratio.

EGR Systems

EGR system used mainly diesel engines to recirculate the exhaust gas through the system; it reduces NOx production by allowing lesser amounts of oxygen content in the engine chamber, leading to lower combustion temperatures (higher the temperature, more harmful the nitrogen oxides are produced). The objective is to provide a low-pressure EGR system for a vehicle mainly ship powered by a diesel engine, preferably heavy-duty engines. The amount of exhaust gas recirculated depends on the engine load. The primary objective being the decline in the increase of particulate matter and corrosive acidic condense water, all the while producing minimal fuel penalty and power consumption.

The investigation showed the reduction of NOx at different loads and took different EGR supply to the engine chamber. Given the many disadvantages with the use of diesel engines taken into consideration ships being run on heavy fuel oil, i.e., marine diesel, one of them being the lack of differential pressure which does not allow for the flow of exhaust gases through the EGR line, also the absence of the throttle to create a vacuum sufficient to drive a slipstream of gases through the EGR loop is seen in most gasoline engines. Diesel engines also are contaminated with soot and particulate matter, which is primarily not found in a gasoline engine. In addition, the recirculation of exhaust gases increases emissions of unburnt fuel components and particulate matter due to deterioration of the combustion process [5].

These challenges can be tackled by countermeasures taken concerning the heavy machinery involved in ships, for example, by using regulating throttles in the intake air system to achieve the pressure difference between the exhaust gas side and intake side, thereby making it possible for high exhaust gas recirculation rates.

The cooled exhaust gas, when recirculated, helps in the decrease of temperature of the engine chamber, which further reduces the production of dangerous nitrogen oxides in the engine chamber

The exhaust gases do not react in the engine chamber because they are inert, and due to the reduction in engine temperature, there will be a decrease in NOx production, which usually takes place at high temperatures [6].

The exhaust gas circulated to decrease the amount of oxygen entering the chamber, keeping the oxygen levels just sufficient for combustion. The exhaust gas is cooled by industrial-sized multi-pipe coolers. The gas, which is around 600°C, goes through the cooling system to come out at a decreased temperature of 125°C. The cooling is made possible by coolants that will travel through the cooler [7].

The release of the exhaust gas is controlled by a valve, which will release the gas according to the desired load that is required by the engine. The given systems have to be equipped with a SOx scrubber system to take care of SOx emissions.

Taking into consideration a container ship of 8500 TEU, with an engine power consumption of 6300 kW and a cruising speed of 14 knots, consuming 26t of heavy fuel oil per day with emission of SO_X, NOx and CO_2 coming at 1.6t, 2.7t and 85.4t per day respectively, along with 3t of particulate matter being emitted out per day. The impact on the environment is huge when you take into account the number of container ships in service at this very instance. The introduction of an EGR system in heavy-duty vessels would come as much needed precedent to the way towards greener shipping [8] (Figures 4–7).

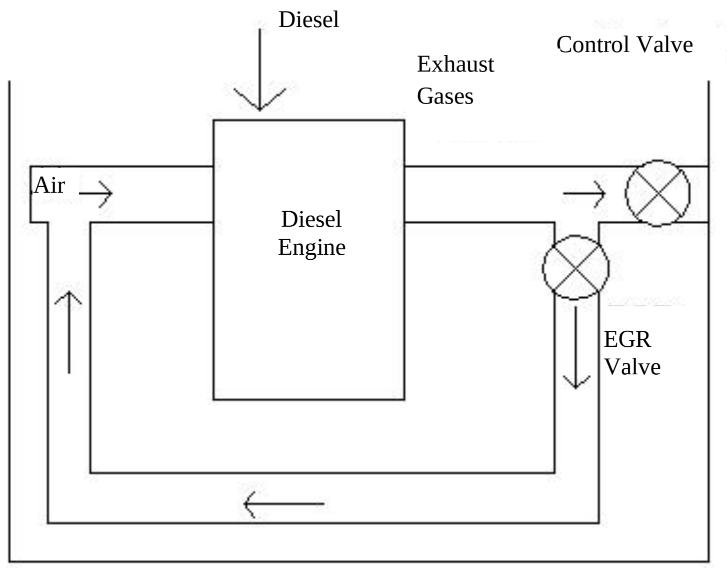

Figure 4. EGR system.

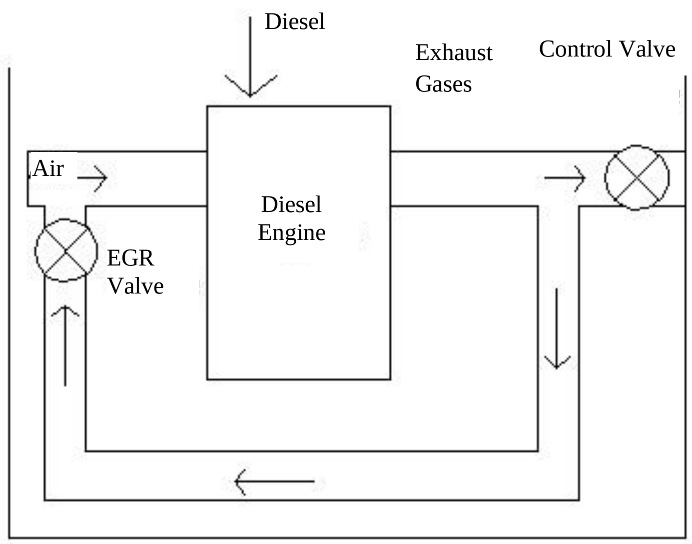

Figure 5. EGR system.

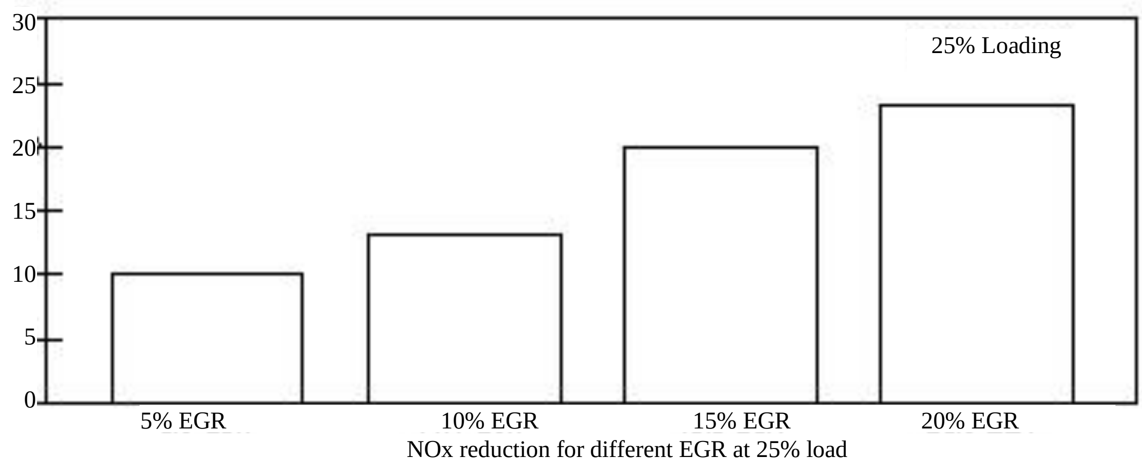

Figure 6. NOx reduction in EGR at 25% load.

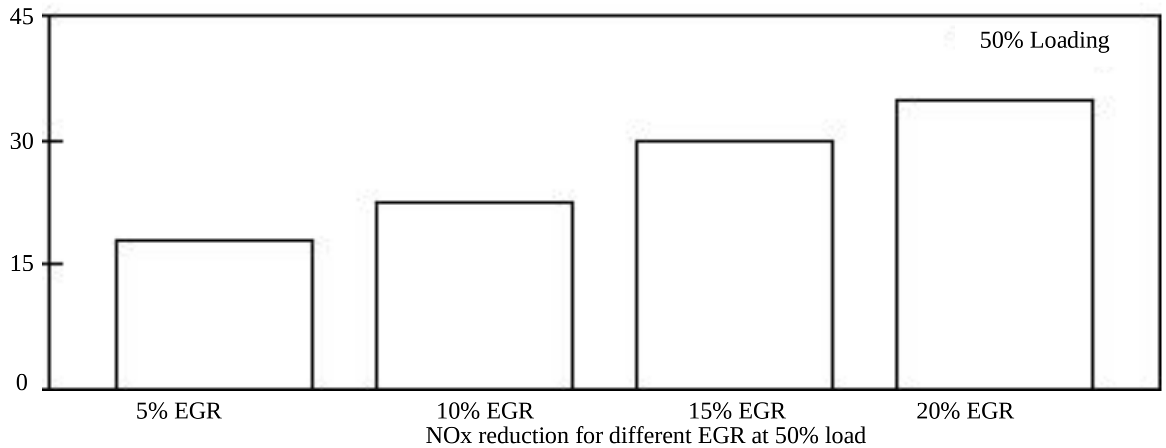

Figure 7. NOx reduction in EGR at 50% load.

The recirculation ratio is controlled based on measured O_2 content in the scavenge air.

Although the EGR system has its benefits, it has additional costs of NaOH, sludge handling, etc., with an increased mechanical load on the engine.

The NaOH consumption depends on the Sulphur content in the fuel, with low Sulphur fuels giving a considerable amount of savings and high sulphur fuel oils depending actually on the Sulphur content.

One of the objectives of this study is to find the efficiency of the EGR system in ships based on different loading conditions and speeds and to combine the system with an SCR system.

O_2 in the scavenge air is replaced with CO_2, which has a higher heat capacity than O_2, which reduces peak temperatures in the cylinder. The cooling of the exhaust gases is also a feasible idea, with the piping system being made longer with bigger diameters to help in the cooling of the gases.

The use of hydrogen gas, used alongside CO_2, which does not react due to its inert nature, is also studied in this paper. It is shown that hydrogen gas has a higher specific heat capacity at higher temperatures than CO_2.

The decrease in the chamber temperature was calculated to see that the peak temperatures are not attained, and NOx production is arrested to an extent [9] (Figure 8).

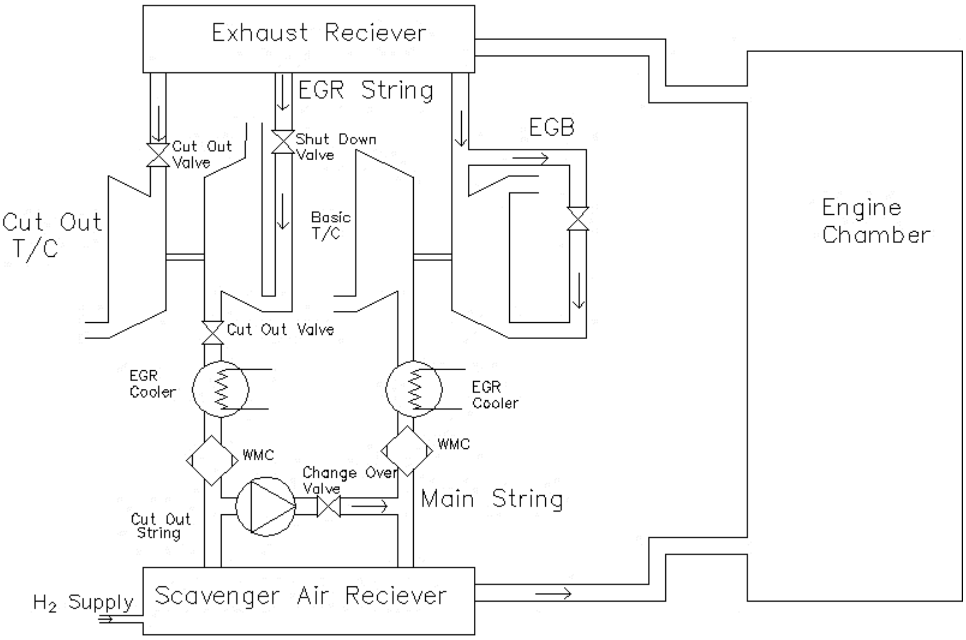

Figure 8. EGR system fitted with H_2 supply valve.

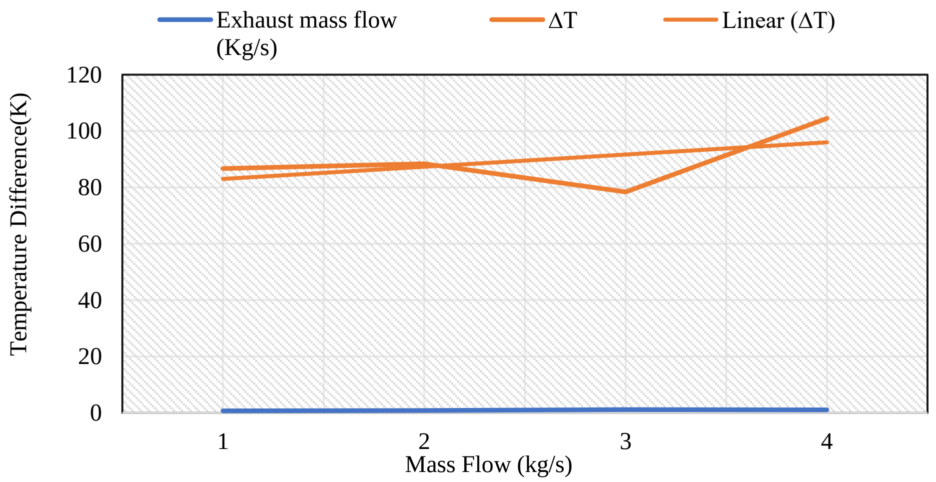

Figure 9. Graph between temperature difference and mass flow.

APPROACH AND PROCEDURE

The effect of inert hydrogen on the system was processed, taking a specific methodology and approximation in mind. A marine diesel engine of 2400 rpm and 260 kWh power rating was taken into consideration. The exhaust gas (Cp of 1.063 kJ/kg) being recirculated with a mass flow of 0.0456 kg/s was combined with the inert hydrogen (Cp of 0.978 kJ/kg) being circulated with an estimated mass flow of 0.392 kg/s, both these elements combined with the surrounding ambient air is pumped into the engine chamber. The air is pumped into the chamber is calculated (refer to table) according to the load of the engine and the required oxygen molecules required for combustion. The air is pumped in the combustion chamber is controlled by a control valve, which lets in the volumetric inflow of 0.01121 m^3/s of the mixture. Cooling is done after combustion inside the chamber due to the high specific heat of the mixture, values of which are given in the table. The temperature difference was found out to be in the range of 85–103 K. A graph (refer graph) was made with the temperature decrease and the exhaust mass flow, which showed the trend that with the increase in the exhaust mass flow, there would also be a decrease in temperature probably due to the expansion of exhaust gas and the velocity with which it is released [10] (Table 3 and Figure 9).

Table 3. Calculation of temperature difference experienced in the chamber.

Temp of the mixture (K)	Exhaust mass flow (kg/s)	Cp of the mixture (kJ/kg)	Exhaust density m^3	DT(K)	Final temp in the chamber (K)
473	0.71808	0.224438255	0.748	86.69511	696.3048931
523	0.853125	0.241154945	0.6825	88.4289	694.5710967
573	1.16613	0.300869067	0.617	78.40258	704.5974182
623	1.1142666	0.264415104	0.52684	104.4788	678.5212261

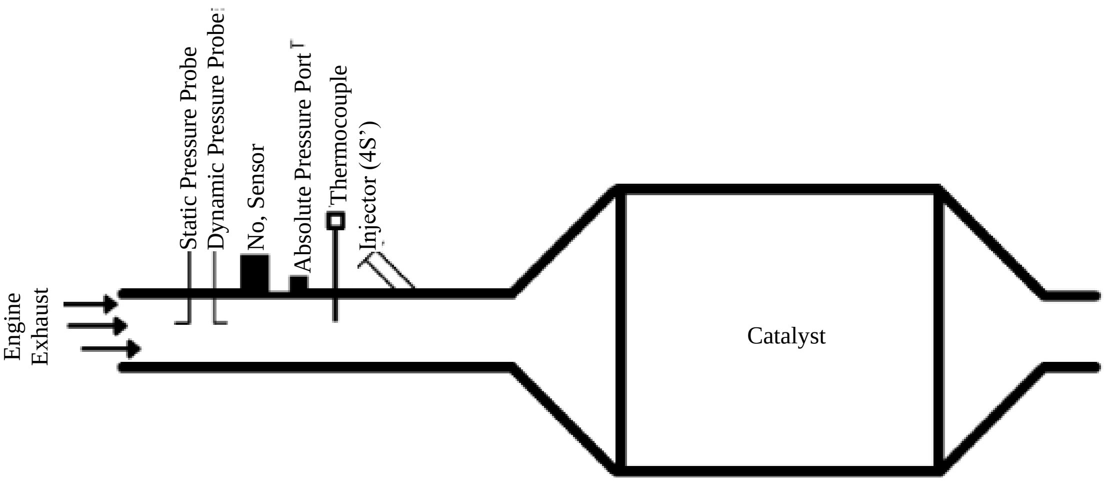

Figure 10. The schematic diagram of a basic SCR setup.

Selective Catalytic Reduction

Selective catalytic reduction (SCR) is an emission control technology system that makes use of reductant agent by catalysing it in the exhaust system of an engine. SCR and effective diesel particulate filter system like SCR-DPF together can bring prominent reduction in NOx and other major pollutants.

SCR for NOx control using ammonia, as the reductant, is a widely accepted method. Ammonia is carried around in a non-hazardous form, as urea solution. Whenever required, Ammonia is generated by the rapid hydrolysis of urea. The balance in amount of urea converted and amount of NO_X formed shows the high feasibility of the SCR system. Detailed urea injection map based on engine information and urea injection based on real time NOx input (NOx sensor based) and calculation logic are the key points to get an accurate balance. Vanadium-based SCR systems are used widely to control NOx emissions. Vanadium-based SCR control catalysts have very high Sulphur tolerance, and, advantageously, vanadium has very high selectivity to nitrogen. The major deactivation mechanisms concerning such catalysts are thermal deactivation and poisoning due to oil-derived species (say, phosphorus). As the thermal demand of on-road market increases (500–600°C), new vanadium-based catalysts are developed to meet high thermal durability. The SCR catalyst consists of vanadium-based catalyst mounted on a ceramic monolith. It is followed by an ammonia slip catalyst which is also coated on ceramic substrates. The engine exhaust flow rate determines catalysts size (in general, it could be 1.5 to 2 times the engine displacement). Ammonia slip catalyst located after SCR catalyst has a volume of 0.5 times the engine displacement [11] (Figure 10).

The SCR system operates independent of electronically communicated engine parameters and utilizes a MotoHawk controller. It can receive all input signals, calculate the amount of urea required for NOx reduction, and deliver a certain amount of eutectic urea solution (Mixture with another compound that do not react with urea) into the engine exhaust. The main input signals for the system are differential pressure created by the exhaust flow within the pipe, absolute pressure, temperature, and NOx concentration. The differential pressure caused from the exhaust gas velocity is obtained from the pressure sensor, both dynamic and static. It is obtained from the Bernoulli's equation of the exhaust flow through the pipes. Air Absolute pressure sensor is used to measure the absolute pressure of the exhaust and a thermocouple is used for temperature measurement. NOx concentration is measured using aNOx sensor which is automotive and has a specified range (range of 0–1500 ppm). It produces a 0–5 volts response which is linearly proportional to the measured NOx concentration. All the above-mentioned sensors are installed upstream of the catalyst and is connected to the controller. The portion of the exhaust piping before the catalyst that contains these sensors is called the flow section.

Exhaust gas from the engine passes through the DPF and then the SCR system. After eliminating CO, HC, and PM from DPF, urea injection takes place. Firstly, urea gets atomized into ammonia (NH_3) through hydrolysis. Then, it reduces the NOx over the SCR catalyst. An additional NH_3 slip control catalyst is also used to ensure complete oxidization of NH_3. The SCR-DPF setup can be basic linear arrangement where slip control catalyst is place after DPF system, or it can be a compact design. We are considering only linear system arrangement for further discussions [12].

The SCR catalyst can be different depending upon various factors, say, vanadium-based catalyst mounted on a ceramic monolith; it is followed by an ammonia slip catalyst which is also coated on ceramic substrates. A few possible catalysts and its properties are analyzed from existing data and tabulated [13] (Table 4).

The engine exhaust flow rate determines catalysts size (in general, it could be 1.5 to 2 times the engine displacement). Ammonia slip catalyst located after SCR catalyst has a volume of 0.5 times the engine displacement. The calculation of NOx concentration is carried out using different chemical and physical parameters like ppm, temperature, pressure, molar mass, volume, etc. In the proposed SCR system, we use the absolute pressure and temperature (measured using the sensors) to calculate the density of the exhaust gas. This along with the velocity and measured NOx concentration, gives the total mass flow rate of NOx. Temperature can also be used to determine the approximate amount of urea that is to be injected [14, 15].

An approximate data analysis can be done to understand the figures involved in the amount of urea and NOx reduction. Considering a marine diesel engine of rated speed 2400 rpm and 260 kWh power. Upon analytical calculations the NOx concentration was found close to the rated value and as the molar ratio of urea to NOx is 0.5:1, for reduction with urea 50% duty cycle, a rough approximation of the required urea could also be found; likewise for 30% DC and 80% DC. Considering that the system runs in a steady state supply of all required energy to the system and a constant flow of exhaust gas at a particular time, NOx concentration trend could be estimated. The NOx sensor of 0–5 V capacity was used (corresponding to 0–1500 ppm). The exhaust gas mass flow was approximated from previous data and similar cases, and it was used to get the mass of NOx transferred. Our calculations were between 200 and 400°C. The temperature control is neglected and it was considered as increasing with time. The average temperature of a time range was approximated to be a constant and the trend was estimated as shown in Table 5 and Figure 11.

Table 4. Possible control catalysts in combination with ammonia and their reaction analysis table.

Catalysts	Precipitation methods	Reaction condition	NOx conversion %
MnO_x	Co–precipitation (100°C)	[NO] = [NH_3] = 500 ppm, [O_2] = 3 vol %, N_2 balance, GHSV = 47,000 h−1	~100% (80–150°C)
MnO_2-TiO_2	Impregnating (400°C)	[NO] = [NH_3] = 500 ppm, [O_2] = 3 vol %, N_2 balance, GHSV = 24,000 h−1	~100% (150–200°C)
VO_x-CeO_2	Hydrothermal (400°C)	[NO] = [NH_3] = 500 ppm, [O_2] = 5 vol %, N_2 balance, GHSV = 120,000 h−1	95–100% (250–350°C)
$Fe_{0.95}Ce_{0.05}O_x$	Co–precipitation (400°C)	[NO] = [NH_3] = 1000 ppm, [O_2] = 3 vol %, N_2 balanced, GHSV = 30,000 h−1	79–100% (175–300°C)

Table 5. Calculation table of NOx reduction trend.

Temp. (K)	t(sec)	NOx (g)	30% reduction	50% reduction	80% reduction
473	100	137.52	96.264	68.76	27.504
	150	206.28	144.396	103.14	41.256
	200	275.04	192.528	137.52	55.008
523	300	629.6703	376.0313	268.5938	107.4375
	350	734.6154	438.7031	313.3594	125.3438
	400	839.5604	501.375	358.125	143.25
	450	944.5055	564.0469	402.8906	161.1563
	500	944.5055	626.7188	447.6563	179.0625
	550	944.5055	689.3906	492.4219	196.9688
573	600	1624.455	1137.119	812.2275	324.891
	650	1759.826	1231.878	879.9131	351.9653
	700	1895.198	1326.628	947.5988	379.0395
	750	2772.303	1421.98	1015.284	406.1138
	800	2423.79	1516.158	1082.97	433.188
623	850	2575.277	1802.694	1287.638	515.0554
	900	2726.764	1908.735	1363.382	545.3528
	950	2878.251	2014.775	1439.125	575.6501
	1000	3029.738	2120.816	1514.869	605.9475

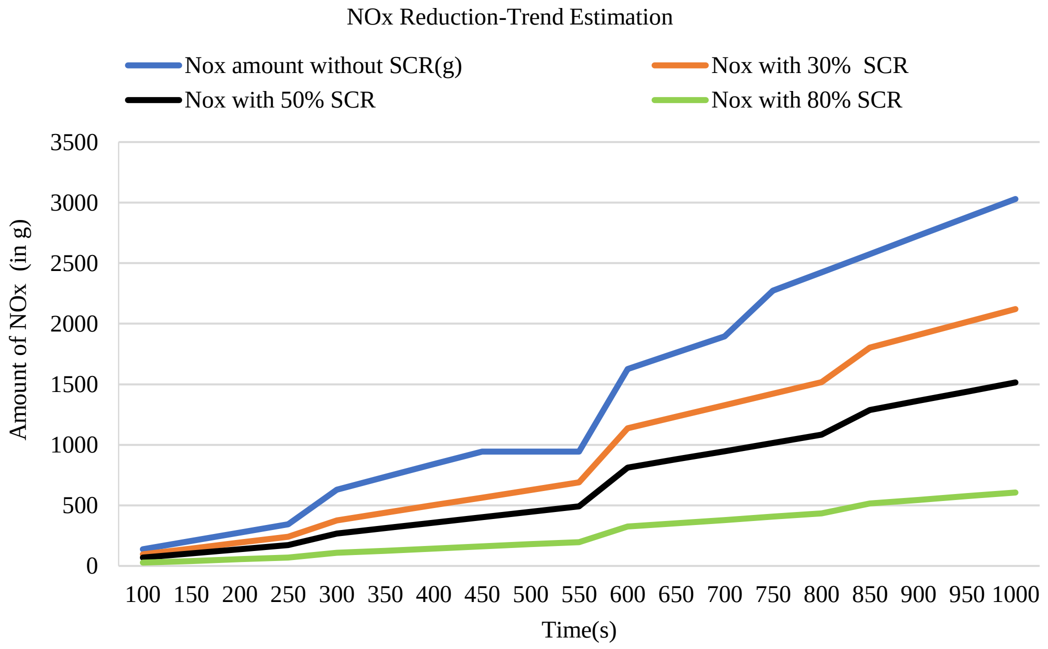

Figure 11. Graph of NOx reduction-trend estimation.

CONCLUSION

A proper LNG re-gasification system means an increased overall efficiency. It would be stressed that proper piping material, thickness of pipes, and the boiler should be decided as per the requirement in a specific case. A layer of insulation coating on the pipes would greatly reduce heat loss, but economically, it might not end up being feasible. Regarding the ambient pressure in the system, care should be taken to ensure that condensation does not occur. Pressure limits will vary inversely with the efficiency of the turbine used.

The use of EGR systems on ships is used in the reduction of NOx reduction in the industry. The proposed EGR system was fitted with a hydrogen valve to supply an inert gas with high heat capacity to decrease the temperature of the mixture after combustion. There was a significant decrease in temperature resulting in the further hindrance of NOx production.

The SCR setup had all the basic equipment required, the usage of a substrate catalyst along with ammonia was considered. The performance result was found to be good from the theoretical study; it is yet to be analyzed further, to check the feasibility and efficiency of this method. A study to obtain a basic estimation of the amount of NOx reduction is also done. The reduction percentage was set to 30, 50 and 80 and a reduction trend for NOx was plotted to depict that the usage of SCR is highly feasible in terms of efficiency and performance.

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