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SIMULATION OF THE RECOVERY OF BOIL-OFF GAS AT LNG STORAGE SECTION AND EXPORTING TERMINALS

Muwarure P.O, Prof. Otaraku I.J, Iriakuma Erempagamo
* Department of Chemical Engineering, University of Port Harcourt, Port Harcourt, Nigeria

KEYWORDS: Boil-off gas, Liquified Nigeria Gas (LNG), Natural Gas, Shipping, Storage, recovery, jetty boil-off gas (JBOG).

ABSTRACT
The model of a Liquefied Natural Gas plant from treatment stage to the shipping section was designed using the Aspen Hysys v8.6 and the Boil of Gas (BOG) occurred at three sections which are depressurization section (also called knock-out/flash drum), the storage section and the shipping section. The purpose of the research was to design a recovery strategy for the boil-off gas at the shipping/jetty section. The following results were obtained as recovery process covered all point of BOG in the plant, 240960kg/day of BOG was recovered from the depressurization and storage tanks while 227952kg/day was recovered from the jetty section during shipping. The composition of the gas from these points are 99.99% methane and 0.0001% ethane. From the research, it was deduced that two integral gear motor compressors of power 1120.52kW at jetty and 1253.52kW at storage and depressurizing sections are suitable for the recovery of the BOG. From the economic analysis, a sum of $3,790,605 will cover the equipment purchase, installation, and an annual running cost while a total of $138,121,200 was obtained from sales of total BOG. With this careful work, the gas flaring issue at the LNG export will be curbed and revenue will rise.

INTRODUCTION
The demand for energy is on a daily increase, hence world production capacity for Liquefied Natural Gas (LNG) is also on the increase. The major component of Liquefied Natural Gas is Methane with some mixture of ethane that has been cooled for ease of safety and transportation James et al, (2006).

For long distances, the most economical way to transport natural gas is in its liquefied form, LNG is six hundred (600) times lower than the volume of its original gas form. However, its bubble point is less than -161oC. This implication requires large amount of energy for liquefaction to occur as stats by Kurle et al, (2015); Kurle et al., (2017) in his work.

The LNG production from the gaseous form of natural gas is somewhat tedious as it involves various steps and procedures. The natural gas first undergoes treatment which is either purification or separation which involves sweetening process to remove acidic gases (CO_2, H_2S); dehydration process to remove water, natural gas liquid (NGL) processing to separate methane (CH_4), ethane(C_2H_4), propane(C_3H_8), and other heavy hydrocarbons such as Pentane plus (C_5+), and LNG processing which involves refrigeration, depressurizing, storing and transportation (Al-Sobhi et al., 2021; Bouabidi et al., 2021)

Parameters: the pressure, temperature volume are put in place to ensure the safety of lives and properties Ravavarapu et al (1996). The difference existing between the temperature of the LNG and the environmental temperature can cause heat to leak without careful insulation. The heat that leaked caused some LNG to vaporize, the generated gas is what is refers to as boil-off gas (BOG). To avoid over-pressure in the LNG carries, it is compulsory to vent off periodically. The BOG usually contains the lightest hydrocarbon from LNG, i.e., methane and ethane. Without a good BOG recovery system, flaring and environmental pollution is inevitable (Pachuari & Meyer, 2014). This will drag down the economic value.

In LNG industries, the boil-off gas issues facing the different sectors of its supply chain has led to a great economic value reduction and environmental degradation. The release of the boil-off gas helps to reduce the excess pressure on the LNG cargo. Lack of the recovery system causes harm to the firm's financial status and the environmental safety (Huang et al, 2007; Garrett, 2018; Verheyleweghen and Jäschke, 2019).

With the tremendous increase in demand for clean energy globally; where LNG is suitable for that. There should also be a protective means for the environment and economic stability. Recovering the jetty boil-off gas (JBOG) at the LNG exporting terminal will prevent greenhouse gas (CH4) emission which is detrimental to both lives and properties in the environment (Wood and Mokhatab, 2007; Saba and Boehm, 2012).

MATERIALS AND METHODS

The process was designed using the Aspen Hysys version 8.6 software and the Soave-Redlich Kwong cubic equation of state was adopted in the entire process. Aspen HYSYS is a chemical process software used by process industries to model and or design a chemical process. In this software, Steady state was assumed throughout.

This work excludes, the treatment and little emphasis was made on the refrigeration section of the natural gas to its liquified form is exempted as the work is focused on only the recovery of the boil- off gas at the storage and jetty section.

FEED DATA

About 95% of the input data used were obtained from the Nigeria Liquefied Natural Gas Limited (NLNG) facts and figure 2018 as shown below.

Table 1. Natural Gas Feed Condition

Pressure [kPa]	5000
Temperature [ºC]	25
Molar Flow [kgmole/h]	1.352×10^5
Mass Flow [kg/h]	2.511×10^6
Vapour/Phase Fraction	0.9842

Table 2. Natural Gas Feed molar composition

Components	**Mole fraction**
Methane	0.883
Ethane	0.0551
Propane	0.0080
n-Butane	0.0075
i-Butane	0.0057
C5+	0.0090
H2O	0.0166
CO2	0.0151

REFRIGERATION UNIT

A three-stage cascade refrigeration system was used in the process with its pure refrigerants which include methane, ethane, and propane. This system was used to first cool the inlet gas until it gradually turned to liquid and at the required temperature. The gas was first passed through Propane, then ethane and finally through methane

PRESSURE RELIEF VALVE

This valve was used to drop the pressure of the LNG before it was sent to the flash drum with a designed pressure below the incoming LNG pressure. A fail shut valve was used in the process.

LNG KNOCK-OUUT DRUM

This drum helped to remove any form of vapour in the LNG stream that could have caused cavitation of the pump while sending LNG to the storage tank. The flashing occurred as a result of the difference in the pressure of the inlet gas and the designed pressure of the flash drum which operates at slightly below 1bar.
The flashing process produced boil-off gas and was recycled

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LNG PUMP AND HEADER TO STORAGE TANK

The pump was used to pump the produced LNG from the flash drum by raising the pressure and through this header, it was distributed to the four storage tanks. The inlet pressure of the LNG to the pump was below atmospheric hence not enough to move the LNG through the distance before storage.

LNG STORAGE TANK

There are four spherical LNG storage tanks designed to store the LNG before it was sent to the jetty section for transportation. Due to the design parameter of the storage tank, the was also boil-off gas which was sent for recycling. The spherical storage tank was used to help prevent liquid hold-up in the tank after discharge

LNG TO JETTY PUMPS

Four jetty LNG centrifugal pump was used to pump the produced LNG from the four storage tanks to the LNG spherical carriers (ships). Each pump is designed with 150KW power and 1800rpm.

LNG CARRIER

Four spherical LNG carriers received the pumped LNG from the storage tank. These carriers are designed below pressure of 1atm with cryogenic properties to in a liquid state. Hence the delivered pressure from the pump is not the same as the receiving vessel.
These carriers are found/located at the jetty area of the plant

JETTY BOG HEADER

The jetty boil-off gas header is a collection manifold that received all the boil-off gas the arose from each spherical LNG carrier and then to the compression section and temperature and pressure were raised for recycling purpose.

JETTY BOG COMPRESSOR

This centrifugal compressor raised condition (T and P) of the jetty boil-off gas from its inlet condition before it mixed with the boil-off gas from KO and storage.

STORAGE AND FLASH DRUM BOG HEADER

The header collected all the BOG in the LNG processing sector excluding the jetty. The KO drum and storage tank BOG are unified in the header. The storage BOG was tagged as TBOG while the KO drum BOG was referred to as DBOG.

TBOG AND DBOG COMPRESSOR

This centrifugal compressor raised the condition of TBOG and DBOG from their inlet conditions to the condition that was suitable for the recycle header.

RECYCLED BOG HEADER

The recycled BOG header served as the collection manifold for the BOG from the jetty section (JBOG) and the BOG from the storage tank and flash drum (TBOG and DBOG).

EQUIPMENT SIZING

The sizing of the equipment was done using the Aspen HYSYS software storage tank, ships and BOG knock-out drums to determine the volumes, diameter, and height.

EQUIPMENT RATING

The rating of some process equipment was performed to determine parameters such as temperature, pressure and the heat duty of the motor compressors and pumps.

RESULT

From the simulation processes on the liquefaction, depressurization, storage, and shipping of the LNG, the boil-off gas was spotted at three sections which are;

1. LNG Depressurization/knock-out drum
2. Storage tanks
3. Shipping section.

The results as listed above are discussed below based on the research requirement.

3b. REFRIGERATION UNIT

The LNG produced from the refrigeration unit contained 96.64% methane and 3.36% ethane. The process parameter of the product (LNG) are -162oC and 3150kPa. the process stream is liquid with mass flowrate of 2002332.46kg/hr. the mass flowrate obtained as LNG was 79.73% of the total natural gas mass flowrate entered the plant. Therefore, 20.27% of the feed where NGL, H_2O and CO_2. See table 4.1a and b

3c. PRESSURE RELIEF VALVE

Across the J-T valve, there was a reduction of pressure from 3150kPa -1500kPa of the LNG and this led to a change of temperature of the LNG from -162 OC to -161.4OC. This caused an increase in the entropy (from 74.74 – 75.34 of the system as gases were produced. The mass and molar flow rate of the LNG were conserved. See table 4.2a and b

3d. LNG KNOCK-OUT DRUM

The knock-out drum was the start point of BOG generation and it removed about 0.32% of LNG total mass flow rate from the refrigeration unit. The BOG was a result of KO design pressure of 100kPa which is lower than the entering pressure of the LNG. The flow rate of KO BOG was 6485kg/h. The knock-out drum functions to ensure no cavitation of pumps. See table 4.3

3ei. STORAGE PUMP

The storage pump added heat to the LNG stream to raise it from - 11023730879.7415 kJ/h to-11021867791.1668kJ/h. this eventually raised the temperature of the LNG to produce another BOG as it enters the ST. See table 44

3eii. HEADER TO STORAGE

The header evenly distributed the LNG coming from the pump to the four ST with equal discharging pressure of 400kPa and temperature of -161.2OC. Although, there is change both in mass flowrate, Molar flow and heat distribution to the tanks and the phase fraction and molar composition are still same. See table 4.5

3f. STORAGE TANKS

The storage tanks produced an equal amount of BOG (888.21kg/h) which summed to 3552.83kg/h and the temperature reduced to -161.3 OC from -161.2OC. The flash resulted due to pressure differences of the tank and the inlet stream. See table 4.6

3g. JETTY PUMPS

The jetty pumps have more discharge pressure compared to the storage tank pump. Therefore, more heat was added. The temperature rose from -161.3 OC to -160.9 OC. This further produced more BOG in the LNG entering the carrier. The four jetty pumps operated/functioned similarly. See table 4.7

3h. LNG CARRIERS AT JETTY

The cryogenic operating condition of the cargos caused more BOG production. A total of 9494.95kg/hr of BOG was produced from the jetty section. See table 4.8

3i. JETTY BOG HEADER

The outlet stream has a combined molar flow(591.6kgmole/h), mass flow((9490.28kg/h) and heat flow of the inlet streams and pressure of 100kPa from the berth BOG streams. The header base elevation was 10m. The composition and every other condition remained the same. See table 4.9

3j. JETTY COMPRESSOR

The compressor outlet condition was 50.75oC and 3500kPa. The phase remained the same and the heat duty of the compressor 4035723.88kJ/h. the output of the jetty BOG from the compressor was easily sent for re-liquefaction. See table 4.10

3k. STORAGE AND KNOCK-OUT DRUM BOG HEADER
The BOG that rose from the storage tank and knock-out drum were more than the jetty BOG. Hence a total mass and molar flow of 10038.4kg/h and 625.7kgmole/hr was collected. But the collection pressure was observed to be 100kPa and the composition and phase fraction remained the same. See table 4.11

3l. STORAGE AND KNOCK-OUT DRUM BOG COMPRESSOR
This compressor raised the temperature and pressure of the BOG from KO and ST to the same pressure and temperature of the jetty compressor. This helped maintain the operating condition before entering reliquefication with the treated natural gas feed. The heat duty of this compressor was more compared to the jetty compressor because more BOG was produced from this section. This implied the produced gas is directly proportional to the compression work. See table 4.12

3n. EQUIPMENT RATING
The rating was for the power-consuming equipment and their duties are shown in table 4.14 above. All the pumps have the same duty but their pressure drop differs. The compressors required more duty and there is pressure and temperature change across them. See table 4.13

3o. MASS BALANCE
The total mass flow from the refrigeration section of the LNG plant and the mass outflow to the shipping section was conserved. The Boil-off gas from the system was fully recovered. No mass loss. The total mass of BOG recovered in the system was 19532.98kg/h. See table 4.14

3p. ENERGY BALANCE
From the energy balance carried on the same section (as mas balance), the overall heat inflow was -11041460429.59 (kJ/hr) the outflow was -11041475119.53(kJ/hr). The energy difference was 14689.94(kJ/hr) and the percentage error was approximately - 0.00013%. Therefore. it is accepted. See table 4.15

3q. ESTIMATED COSTING OF BOG RECOVERY EQUIPMENT
The costing of the equipment was centered on the BOG recovery alone. And table 4.18 displayed the financial implications of the major equipment needed for efficient recovery. The compressor purchased was based on specification of the BOG from the jetty section and the storage and Knock-out drum section. See table 4.16

3s. ANNUAL INCOME FROM BOG
Based on the flowrate obtained in the simulation process, the BOG with a flowrate of 240,969kg/day from KO and storage with the plant operating for 330 days and 227,952kg/day from berth for 100days, Table 4.19 above shows the total annual revenue of
$138,121,200.00 obtained from recycling the BOG at methane price per kg of $1.35. See table 4.17

3t. PROFIT ANALYSIS ON BOG RECOVERY
The break-even which is the point where sales exactly covered expenses were obtained as $ 3,895,791.4 and this implied a profit worth of $ 134,225,408.60 was realized. Although payment of manpower for production was not included.

TABLES OF RESULTS

4.1 REFRIGERATION UNIT

The LNG produced from the refrigeration unit has the following results stated below:

Table 4.1a Process condition of LNG result

Components	Mole fraction	Mass Fraction (%)
Methane	0.9664	96.64
Ethane	0.0336	3.3600
Propane	0.0000	0.0000
n-Butane	0.0000	0.0000
i-Butane	0.0000	0.0000
C5+	0.0000	0.0000
H_2O	0.0000	0.0000
CO_2	0.0000	0.0000
Total	1.0000	100.00

4.2 J-T VALVE

The check valve used was opened 50%.

Table 4.2a J-T Valve results

Parameter	Inlet stream (LNG)	Outlet stream (TODEP)
Phase	0.0000	0.0000
Temperature (°C)	-162.0	-161.4
Pressure (kPa)	3150	1500

4.3 KNOCK-OUT DRUM

Table 4.3 Result of the knock-out (KO) drum

Parameter	Inlet (from JT Valve)	Liquid Outlet (to pump)	Vapour Outlet (BOG)
Phase fraction	0.0000	0.0000	1.0000
Temperature (°C)	-161.36	-161.31	-161.31
Pressure (kPa)	1500.00	100.00	100.00
Molar flow(kgmole/h)	1.229×10^5	1.224×10^5	404.213
Mass flow (Kg/h)	2.002×10^6	1.996×10^6	6484.93
Component	**Mole fraction**	**Mole fraction**	**Mole fraction**
Methane	0.9818	0.9817	1.0000
Ethane	0.0182	0.0182	0.0000
Total	1.0000	1.0000	1.0000

4.4 STORAGE PUMP

The Pump heat duty was computed to be 1.863× 106 kJ/h (517.5KW) using Hysys and was calculated based on the pressure difference between suction and discharge pressure.

Table 4.4 Storage Pump result

Parameter	Inlet to pump	Outlet to storage header
Vapour	0.0000	0.0000
Temperature [C]	-161.31	-161.16
Pressure [kPa]	100.00	400.0
Molar Flow [kgmole/h]	1.224×10^5	1.224×10^5
Mass Flow [kg/h]	1.996×10^6	1.996×10^6
Heat Flow [kJ/h]	-1.102×10^{10}	-1.102×10^{10}
Component	**Mole fraction**	**Mole fraction**
Methane	0.9817	0.9817
Ethane	0.0183	0.0183
Total	1.0000	1.0000

Table 4.1b LNG stream composition

Phase fraction	0.0000
Temperature (°C)	-162.0
Pressure (kPa)	3150
Molar flow (Kgmole/h)	1.229×10^5
Mass Flow(kg/h)	2.002×10^6

Table 4.2b J-T Valve product composition

Component	Mole fraction
Methane	0.9818
Ethane	0.0182
Others	0.0000
Total	1.0000

4.5 LNG HEADER TO STORAGE

The LNG header evenly distributes the LNG to the four storage tanks.

Table 4.5 LNG header to four storage tanks

Name	Inlet to header	To Storage 1	To Storage 2	To Storage 3	To Storage 4
Vapour	0.0000	0.0000	0.0000	0.0000	0.0000
Temperature [C]	-161.2	-161.2	-161.2	-161.2	-161.2
Pressure [kPa]	400.00	400.00	400.00	400.00	400.00
Molar Flow [kgmole/h]	1.224×10^5	3.061×10^4	3.061×10^4	3.061×10^4	3.061×10^4
Mass Flow [kg/h]	2.002×10^6	4.989×10^5	4.989×10^5	4.989×10^5	4.989×10^5
Heat Flow (KJ/h)	-1.102×10^{10}	-2.755×10^9	-2.755×10^9	-2.755×10^9	-2.755×10^9

4.6 LNG STORAGE TANK

Each tank capacity is 84,200m3. The result is same in all four tanks.

Table 4.6a LNG storage tank result

Name	To Storage 1 (Inlet)	Liquid in tank	BOG from tank
Vapour	0.0000	0.0000	0.0000
Temperature [C]	-161.2	-161.3	-161.3
Pressure [kPa]	400.00	100.00	100.00
Molar Flow [kgmole/h]	3.061×10^4	3.061×10^4	55.36
Mass Flow [kg/h]	4.989×10^5	4.981×10^5	888.2
Std Ideal Liq Vol Flow [m3/h]	1658	1655	3.000
Molar Enthalpy [kJ/kgmole]	9.001×10^4	9.001×10^4	-8.128×10^5
Molar Entropy [kJ/kgmole-C]	75.61	75.57	75.61
Heat Flow (KJ/h)	-2.755×10^9	-2.755×10^9	-2.755×10^9

Table 4.6b Molar composition of LNG in the storage tank

Component	Liq. Mole fraction	BOG Mole Fraction
Methane	0.9817	1.0000
Ethane	0.0183	0.0000
Total	1.0000	1.0000

4.7 LNG TO JETTY PUMPS

There are four pumps to jetty section which supplies LNG to LNG carrier ships. From the simulation process, each pump was given the same rating and it was observed to have the same readings as shown below

Table 4.7 Jetty pumps result

Parameter	An inlet to the jetty pump	Outlet to the LNG carrier
Vapour	0.0000	0.0000
Temperature [C]	-161.3	-160.9
Pressure [kPa]	100.00	900.0
Molar Flow [kgmole/h]	3.056×10^4	3.056×10^4
Mass Flow [kg/h]	4.981×10^5	4.981×10^5
Std Ideal Liq Vol Flow [m3/h]	1655	1655
Molar Enthalpy [kJ/kgmole]	-9.003×10^4	-8.998×10^4
Molar Entropy [kJ/kgmole-C]	75.57	75.66
Heat Flow [kJ/h]	-2.751×10^9	-2.750×10^9
Component	**Mole fraction**	**Mole fraction**
Methane	0.9817	0.9817
Ethane	0.0183	0.0183
Total	1.0000	1.0000

4.8 LNG CARRIER AT JETTY

The spherical LNG carrier is a cryogenic container.

Table 4.8 LNG Carrier result

Parameter	Outlet to the carrier	Stored LNG in the Ship	Vapour Outlet (BOG)
Vapour	0.0000	0.0000	1.0000
Temperature [C]	-160.9	-161.31	-161.31
Pressure [kPa]	900.0	100.00	100.00
Molar Flow [kgmole/h]	3.056×10^4	3.041×10^4	147.9
Mass Flow [kg/h]	4.981×10^5	4.957×10^5	2373
Molar Enthalpy [kJ/kgmole]	-8.998×10^4	-9.003×10^4	8.128×10^4
Molar Entropy [kJ/kgmole-C]	75.66	75.57	150.26
Heat Flow [kJ/h]	-2.750×10^9	-2.738×10^9	-1.202×10^7
Component	**Mole fraction**	**Mole fraction**	**Mole fraction**
Methane	0.9817	0.9816	1.0000
Ethane	0.0183	0.0184	0.0000
Total	1.0000	1.0000	1.0000

4.9 JETTY BOIL OF GAS HEADER

This was the collection point of all the BOG from the jetty area. The outlet stream of the mixer was set to the lowest pressure of the inlet streams

Table 4.9 Jetty BOG header result

Parameter	Ship 1Tank 1 (BOG)	Ship 1 Tank 2 BOG	Ship 1 tank 3 BOG	Ship 1 Tank 4 BOG	BOG to J-Compressor
Vapour	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature [C]	-161.31	-161.31	-161.31	-161.31	-161.31

Pressure [kPa]	100.00	100.00	100.00	100.00	100.00
Molar Flow [kgmole/h]	147.9	147.9	147.9	147.9	591.6
Mass Flow [kg/h]	2372.57	2372.57	2372.57	2372.57	9490.28
Heat Flow [kJ/h]	-1.202× 107	-1.202× 107	-1.202× 107	-1.202× 107	-4.808× 107
Component	Mole fraction	Mole fraction	Mole fraction	Mole fraction	Mole fraction
Methane	1.0000	1.0000	1.0000	1.0000	1.0000
Total	1.0000	1.0000	1.0000	1.0000	1.0000

4.10 JETTY BOG COMPRESSOR

The motor compressor with a duty of 1120.52kW was used to raise the temperature and pressure of the jetty boil-off gas before the general BOG header.

Table 4.10 Jetty BOG Compressor result

Parameter	Compressor inlet (JBOG from the header)	To GENERAL BOG header
Vapour	1.0000	1.0000
Temperature [C]	-161.31	50.75
Pressure [kPa]	100.00	3500
Molar Flow [kgmole/h]	591.6	591.6
Mass Flow [kg/h]	9490.28	9490.28
Molar Entropy [kJ/kgmole-C]	150.26	155.90
Heat Flow [kJ/h]	-4.808×10^{7}	-4.404×10^{7}
Component	**Mole fraction**	**Mole fraction**
Methane	1.0000	1.0000
Total	1.0000	1.0000

4.11 BOG FROM STORAGE AND LNG KNOCK-OUT DRUM HEADER

The table below displays the result of the BOG generated from the four storage tanks and the knock-out drums. The outlet of the header was set to the lowest pressure of the inlet streams.

Table 4.11 STORAGE AND KNOCK-OUT DRUM HEADER RESULT

Name	Knock-out BOG	Tank 1 BOG	Tank 2 BOG	Tank 3 BOG	Tank 4 BOG	Outlet to comp.
Vapour	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature [C]	-161.31	-161.31	-161.31	-161.31	-161.31	-161.31
Pressure [kPa]	100	100	100	100	100	100
Molar Flow [kgmole/h]	404.25	55.36	55.36	55.36	55.36	625.7
Mass Flow [kg/h]	6485.47	888.23	888.23	888.23	888.23	10038.4
Heat Flow [kJ/h]	-3.286×10^{7}	-4.50×10^{6}	-4.50×10^{6}	-4.50×10^{6}	-4.50×10^{6}	-5.09×10^{7}

4.12 STORAGE AND KNOCK-OUT DRUM BOG COMPRESSOR

The electric motor compressor has a duty of 1253.52kW

Table 4.12 Storage and knock-out drum (SK) BOG Compressor result

Parameter	Compressor inlet (SKBOG from the header)	To GENERAL BOG header
Vapour	1.0000	1.0000
Temperature [C]	-161.31	50.75
Pressure [kPa]	100	3500
Molar Flow [kgmole/h]	625.7	625.7
Mass Flow [kg/h]	10038.4	10038.4
Heat Flow [kJ/h]	-5.09×10^7	-4.659×10^7
Component	**Mole fraction**	**Mole fraction**
Methane	1.0000	1.0000
Total	1.0000	1.0000

4.13 EQUIPMENT RATING

Equipment rating was simulated on cooler, compressor, pump and pressure control valve. Result is displayed in table.

Table 4.13a Equipment Rating of Pumps and Compressors

PARAMETERS	COMPRESSORS		PUMPS				
	JETTY	STORAGE	LNG STORAGE	JETTY PUMP 1	JETTY PUMP 2	JETTY PUMP 3	JETTY PUMP 4
Change in Temperature (°C)	212.05	212.05	0.1	0.6	0.6	0.6	0.6
Change in Pressure (kPa)	3400	3400	300	800	800	800	800
Duty (kW)	1121.03	1185.17	344.394	344.394	344.394	344.394	344.394

Table 4.13b Equipment Rating of Pressure Control Valve

PARAMETERS	PCV
Change in Temperature (°C)	0.6
Change in Pressure (kPa)	1650
Change in Mass Flow(kg/hr)	0
Valve opening (%)	50

Where PCV=Pressure Control Valve

4.14 MASS BALANCE

The total mass balance of the concentrated area is shown in table 4.16 below.

Table 4.14: Total Mass Balance

Stream	Mass Inflow (kg/hr)	Stream	Mass outflow (kg/hr)
LNG	2002329.215	Ship 1 BOG	2374.318092
		Ship 1 LNG	495697.5648
		Ship 2 BOG	2374.288332
		Ship 2 LNG	495697.5947
		Ship 3 BOG	2374.288347
		Ship 3 LNG	495697.5947
		Ship 4 BOG	2371.650514
		Ship 4 LNG	495700.2325
		KO BOG	6485.206154
		Storage tank 1 BOG	889.1192691
		Storage tank 2 BOG	889.1192694

		Storage tank 3 BOG	889.1192694
		Storage tank 4 BOG	889.1192694
Total	2002329.215		2002329.215
Difference = Mass inflow – Mass Outflow = 0.0000			
Hence % error = 0.0%			

KO: knock-out drum, BOG: Boil Off gas, LNG: Liquefied Natural Gas

4.15 ENERGY BALANCE

The inlet and outlet heat flow of the concentrated system are summarized in the tables 4.17.

Table 4.15: Total Energy Balance

Inflow Stream	Heat Inflow (kJ/hr)	Outlet Stream	Heat outflow (kJ/hr)
LNG	-11056585155	JLNG1	-2737712594.82511
TCOMP	4266627.479	JLNG	-2737698391.85143
JBCQ	4035723.883	JLNG 2	-2737698449.86276
LQ	1863088.575	JLNG 3	-2737698449.83266
SQ3	1239821.537	BOG	-90667232.16038
TH	1239821.537		
SQ1	1239821.537		
SQ	1239821.537		
Total	**-11041460429.59**		**-11041475119.53**
	%Error	-0.00013%	

4.16 ESTIMATED COSTING OF BOG RECOVERY EQUIPMENT

Table 4.16 Cost of BOG Recover compressors

Name of Equipment	Type of Equipment E	Total Direct Cost (USD)	Equipment weight (lbs)	Installed weight (lbs)
Jetty Compressor	DGC IG CENTRIF	969,600.0	21000	44524
Storage and knock-out drum compressor	DGC IG CENTR IF	974,300.0	21000	44430
The total cost of Equipment (TCE)		1,943,900.0		
Installation	10% TCE	194,390.0		
Instrumentation	5% TCE	97,195.0		
Piping	15% TCE	291,585.0		
electrical	6%TCE	116,634.0		
Working Capital	15%TCE	291,585.0		
Construction	10% TCE	194,390.0		
contractor's fee	5% TCE	97,195.0		
contingency	10% TCE	194,390.0		
yard improvement	4% TCE	77,756.0		
service facilities	15% TCE	291,585.0		
The total cost of investment (TCI)		3,790,605.0		

BOG-Boil-Off Gas, USD-United State Dollar, lbs- Pounds DGC IG- Integral compressor
Total Startup cost for BOG Recovery = $ 3,790,605.0

4.17 ANNUAL INCOME FROM BOG

Table 4.17 Annual income from BOG Recycling

PRODUCT	Volume (kg/day)	Price ($/kg)	Production (days)	Total Amount ($)	Total Yearly income ($)
BOG from production	240,960	1.35	330	107,347,680.00	**138,121,200.00**
BOG from shipping	227,952	1.35	100	30,773,520.00	

4.18 PROFIT ANALYSIS ON BOG RECYCLING

The BOG profit analysis for recycling process is shown as follows;

$$\text{Gross Profit Margin} = \frac{\text{Net Sales} - \text{Cost of materials}}{\text{Net Sales}} \times 100 = \mathbf{97.3\%}$$

$$\text{Break-Even} = \frac{\text{Fixed Cost}}{\text{Gross Profit Margin}} = \$\ \mathbf{3{,}895{,}791.4}$$

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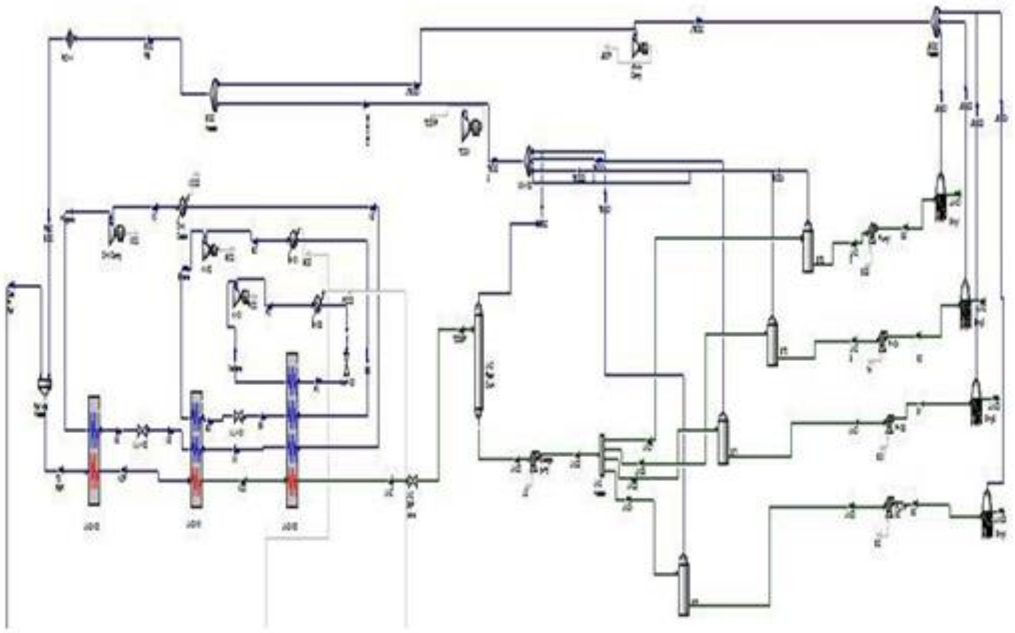

Fig1. Simulation of process using Aspen Hysys