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Simulation and Optimization of an Innovative Dual Mixed Component Refrigerant Cycle (DMRC) for Natural Gas Offshore Liquefaction Plants

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Abstract

Simulation and optimization of an innovative liquefaction process used for the LNG production , namely the Dual Mixed Refrigerant Process (DMRC) has been conducted using the HYSYS simulator .This new process is especially suitable for off shore natural gas liquefaction plants. A numerical optimization technique has been used to determine the optimum conditions for Egyptian natural gas feed source. The investigation of the effect of different compositions of the Mixed refrigerants used was conducted. Meanwhile, the investigation of the influence of the temperature of cooling water used was conducted. The best optimum conditions for the DMRC process were determined .The optimum results achieved for the DMRC process revealed that the DMRC process can be successfully applied as a promising technique for off shore natural gas liquefaction plants.

Introduction

Currently three major commercial processes are available for LNG production, the Single Mixed-Refrigerant Process and it's modification (Propane Pre-Cooled Mixed-Refrigerant Process), the Cascade Process , and the Turbo Expander process.

Since the early 1980s the propane mixed refrigerant process (P-MRC) was used for most of the new liquefaction plants around the world. (Simon Bonimi,2001).

Numerous process cycles have been developed for LNG production to provide the large refrigeration requirements for liquefaction . Such cycles typically utilize combinations of single component refrigeration systems using propane . Well-known mixed refrigerants typically comprise light hydrocarbons and optionally nitrogen and utilize compositions tailored to the temperature and pressure levels of specific process steps.

The objectives in the design and operation of current LNG process cycles and equipment have been to minimize energy consumption and maximize LNG production while operating at changing product demand rates and varying ambient temperature conditions. Since LNG production facilities are typically land-based in remote locations , the land area required for plant battery limits has not been a critical factor in plant design and layout.

Most large LNG production plants employ a propane refrigerant cycle to precool the feed gas prior to further cooling and liquefaction by means of multicomponent or mixed refrigerant cycles . The propane pre cooled cycle , has very efficient and cost effective in land-based plants ,while has certain disadvantages for shipboard or barge applications . The necessity of maintaining fairly large quantities of propane presents potential safety concerns , and the numerous propane evaporators consume scarce plot plan area .(Roberts,2001)

An innovative liquefaction technique for the LNG production , namely the DMRC was recently presented by (Roberts,2001) . This new technique is especially suitable for off shore natural gas liquefaction plants since it requires smaller land area and lower number of equipments . Till now no published data are available about the optimum conditions for the operation of the DMRC process.

The main objective of this work is to simulate and optimize this innovative (DMRC) process which enables determing the proper evaluation of the natural gas liquefaction plant performance.

Process description of the (DMRC):

A simplified flow chart of the DMRC used is presented in Fig.(1).) Pretreated natural gas (N1) enters the first heat exchanger (LNG1) and is cooled therein to an intermediate temperature ,The actual temperature level of this cooling level depends on the feed composition and desired LNG product specification . Cooling in LNG1 is effected by the worming and vaporization of the high level refrigerant (R1-1)

Cooled feed (N2) is introduced into reboiled stripper or scrub column (demethanizer) for the removal of hydrocarbons heavier than methane. The top product from this column (N3) is further cooled an liquefied in the second heat exchanger (LNG2) by indirect heat exchange by worming and vaporizing stream (R2-1) .The resulting liquefied product stream (N4) , typically liquefied natural gas (LNG), is flashed by adiabatic pressure reduction to a low pressure across throttling valve .

The stream (R1-8) is the high level mixed refrigerant after compression and cooling, and typically contains some condensed liquid. . The stream enters (LNG1) at ambient temperature and elevated pressure , and is then condensed, cooled, and optionally sub cooled exiting as stream (R1-9) which is then flashed adiabaticaly to a low pressure across the throttling valve (stream R1-1), R1-1 is introduced to the cold end of heat exchanger (LNG1) and then it is wormed and vaporized in it leaving it as a vapor refrigerant stream (R1-2) which is then compressed in a multistage compressor then cooled (R1-4). Liquid refrigerant may be produced so it is better to separate the two phases in a separator then compressing the vapor stream produced (from (R1-5V)TO (R1-6V)) , and similarly pumping liquid from (R1-5L) to (R1-6L). then mixing the liquid and vapor to form stream (R1-7) which is then cooled to stream (R1-8).

The low level refrigerant loop is similar to that of the high refrigerant .Compressed low level stream (R2-6) enter exchanger (LNG1) and is cooled therein and exiting as a cooled low level refrigerant stream (R2-7) , which is further cooled and optionally sub cooled in LNG2 to stream (R2-8) then by flashing it in a throttling valve to stream (R2-1) ,introducing it to the cold end of (LNG2) , where it vaporized to provide refrigeration therein. This vapor stream (R-2) leaving the heat exchanger is then compressed and after cooled .(Roberts,2001)

Methodology :

Simulation of the process has been conducted using the HYSYS simulator version 1.5. The Uni-Varient search method for numerical optimization was applied to determine the optimum conditions for Egyptian natural gas feed source presented in Tables (1,2) .Fig.(2) depicts the Uni-Varient chart used .

The objective function used to be minimized in this work is the sum of the following cost items : annual cost of power consumption in compressors , annual cost of cooling water in coolers , and annual depreciation cost of heat exchangers area .The results are restricted to minimum temperature approach in main heat exchanger (LNG1 , LNG2) of 3°C , to account for the uncertainty in the EOS calculations.

Objective Function = Annual cost of power consumption + Annual cost of cooling water in coolers + Annual depreciation cost of heat exchangers area.

Subjected to : Minimum temperature approach in LNG 1 , LNG2 >3 .

The basic data used for cost estimation are summarized in table 3. The equation of state used in this simulation is PRSV(Peng-Robinson Stryjek-Vera) which is believed to be the best EOS that can be used for the cryogenic conditions,(Tamer Samer,2001), which is presented by the following equation:

$$\frac{RT}{\bar{V}-b} - \frac{a}{\bar{V}(\bar{V}+b)+(\bar{V}-b)}$$

The parameters investigated in this work are :

1.Compositions of the high level refrigerant (HLR) and the low level refrigerant (LLR) .

2.Temperature of cooling water used.

Results and Discussion :

Figures (3-5) depicts the optimum LLR compositions at different HLR1-HLR2-HLR3 compositions .Tables (4-5) Summarize the composition of HLR1,HLR2,HLR3.The optimum conditions of the DMRC process is presented in Fig(6) and Table (6). The influence of temperature of cooling water on different cost items at optimum conditions is presented in Fig (7).

From the above figures and tables it is obvious that :

1. Due to the interaction between the two mixed refrigerants LLR and HLR it was found that the DMRC processes performance was very sensitive to Nitrogen and Methane contents in the LLR , and the Ethane content in the HLR.

2. The cooling water temperature has a considerable effect at the global optimum on various cost items .

3- A comparison of the specific power requirement for various existing liquefaction plants is shown in Fig.(8).

4- A significant reduction in power consumption for the DMRC process is attained over two recent – built liquefaction plants . About 14% reduction over that of Qatar gas plant and about 2% reduction over that of Malaysia LNG2 plant.

Conclusions:

The optimum results achieved for the DMRC process revealed that the DMRC process can be successfully applied as a promising technique for off shore natural gas liquefaction plants. The results found revealed that The DMRC process required smaller land area , lower number of equipments , smaller flow rates of both refrigerants and cooling water . Therefore the DMRC process is the most suitable technique of the natural gas off shore liquefaction plants

The conclusion reached in this work are believed to be important, and it is hoped that the present results will contribute to the understanding of the sensitivity of the process performed.

We believe that an interesting extension of this work is to obtain a more generalized picture of the discussed process through a thorough investigation of the performance characteristics of the modified DMRC process for the liquefaction of natural gas involving three or more mixed refrigerant cycles.

References :

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- Tamer Samer, Modeling, *Simulation and optimization of a liquefied Natural Gas plant using propane pre-cooling mixed refrigerant cycle as applied to Egyptian sources of natural gas* , M.A. to Cairo University-Faculty of Engineering ,Chemical Engineering Department 2001.
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- Beveridge, G.S. & R.S Schechter , *Optimization : Theory and Practice* , Mc. Graw Hill , (1970) .

Symbols :

P : pressure , (bar)

a: : equation of state constant

b :equation of state constant

R : universal gas constant

$\bar{V}$: molar volume

PRSV: Peng-Robinson Stryjek-Vera equation of state

LE : Egyptian Pound

Table (1) : Natural gas feed source and compositions,(EGPC,2000)

	Port-Fouad well composition %(mole)
C1	93.72
C2	2.92
C3	1.53
n-C4	0.43
i-C4	0.48
n-C5	0.19
i-C5	0.14
C 6+	0.25
CO2	0.34
Total	100

Table (2) : Natural gas feed specifications,(EGPC,2000)

Temperature	35°C
Pressure	65 bar
Treatment	Dehydrated and Sweeted
Processes capacity	3.6 MMtpy of LNG with 800 h/year working hours

Cost of Cooling Water	0.15 LE / ton. Water
Depreciation Time For Heat Exchangers	10 years
Calorific Value of Natural Gas	38,612 KJ/m^3 , (EIA,2001)
Working Hours	8000hr/year
Thermal Efficiency of Gas Turbines	38% , (Perry, 1997)
Overall design heat transfer coefficient,U	250 W/m^2 °k (for MR coolers) 625 W/m^2 °k (for Propane-MR exchangers) 200 W/m^2 °k (for Propane-natural gas exchangers) 850 W/m^2 °k (for propane coolers) (Kern,1950, as cited in Samer,T,2001)

Note :All costs based on year (2001) costs

Table (3) : Data used for optimization of the DMRC process

High-Level-Refrigerant

	C1%	C2%	C3%	I-C4%	n-C4%
COMP (1-A)	1	40	9.5	9.5	40
COMP (1-B)	1	40	7	7	45
COMP(1-C)	1	40	4.5	4.5	50
COMP(2-A)	1	45	7	7	40
COMP(2-B)	1	45	4.5	4.5	45
COMP(2-C)	1	45	2	2	50
COMP(2-D)	0	45	0	0	55
COMP(3-A)	1	50	4.5	4.5	40
COMP(3-B)	1	50	2	2	45
COMP(3-C)	0	50	0	0	50

Table (4): Different compositions of the HLR used

Low-Level-Refrigerant

	C1%	C2%	C3%	N2%
COMP(33-10)	33	43	14	10
COMP(33-12)	33	42	13	12
COMP(33-14)	33	41	12	14
COMP(33-16)	33	40	11	16
COMP(35-10)	35	42	13	10
COMP(35-12)	35	41	12	12
COMP(35-14)	35	40	11	14
COMP(35-16)	35	39	10	16
COMP(37-12)	37	40	11	12
COMP(37-14)	37	39	10	14
COMP(37-16)	37	37.5	9.5	16
COMP(37-17)	37	37	9	17

Table (5): Different compositions of the LLR used

Composition Of MR (Mole Fraction)	High Level Refrigerant	Low Level Refrigerant
C1%	1	35
C2%	45	41
C3%	2	12
i-C4%	2	-
n-C4%	50	-
N2%	-	12

Table(6): Optimum compositions of HLR and LLR at optimum condition. for the DMRC process.

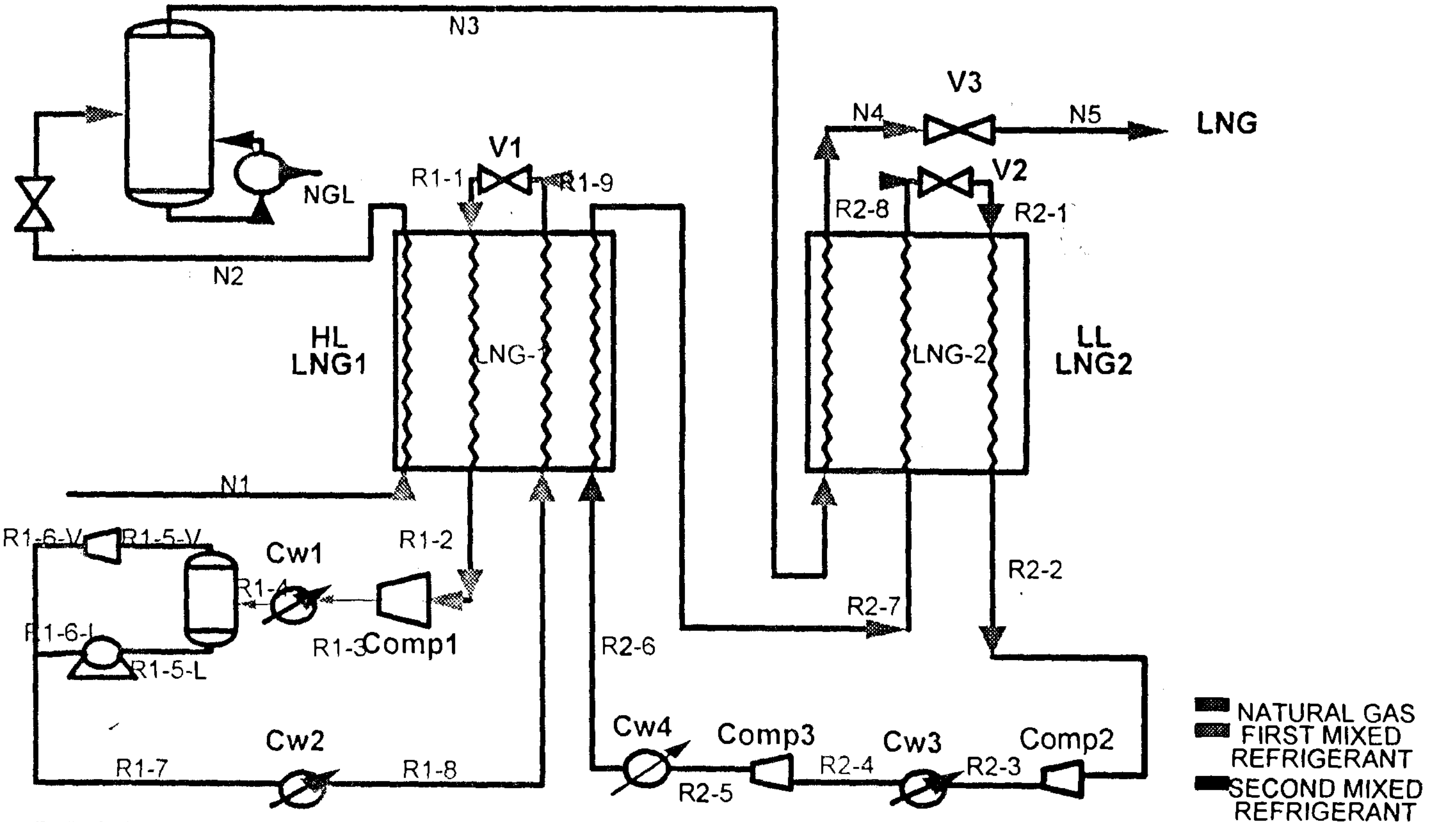

Figure (1) : Dual Mixed Refrigerant Cycle

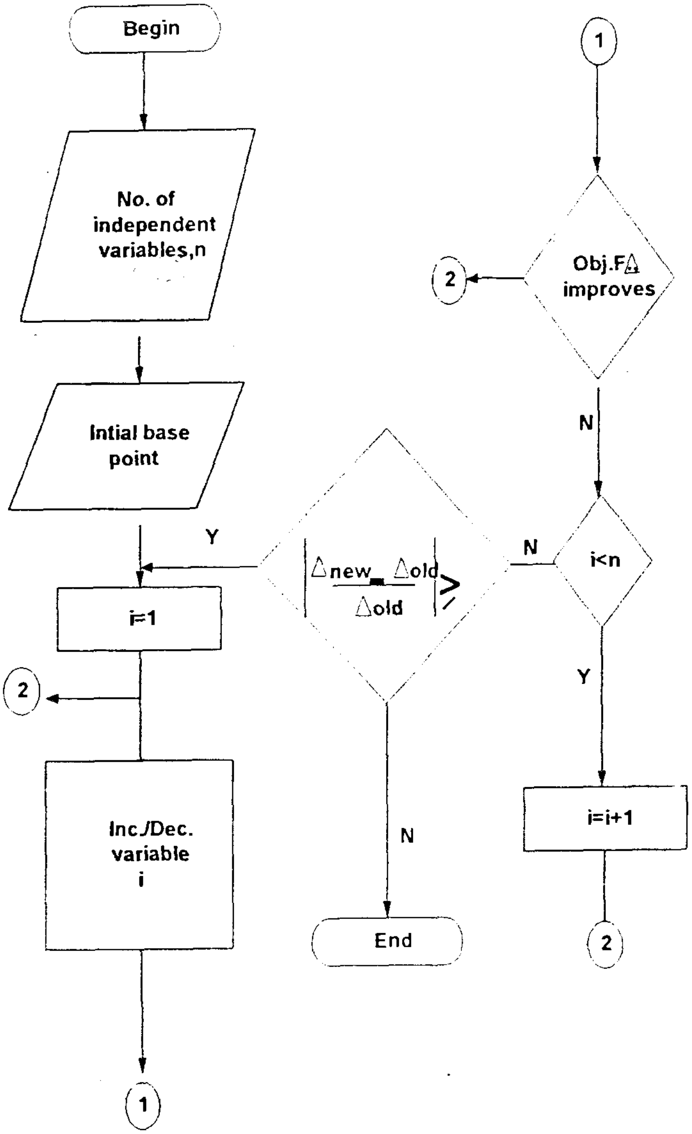

Fig.(2) : Uni-Varient method flow chart

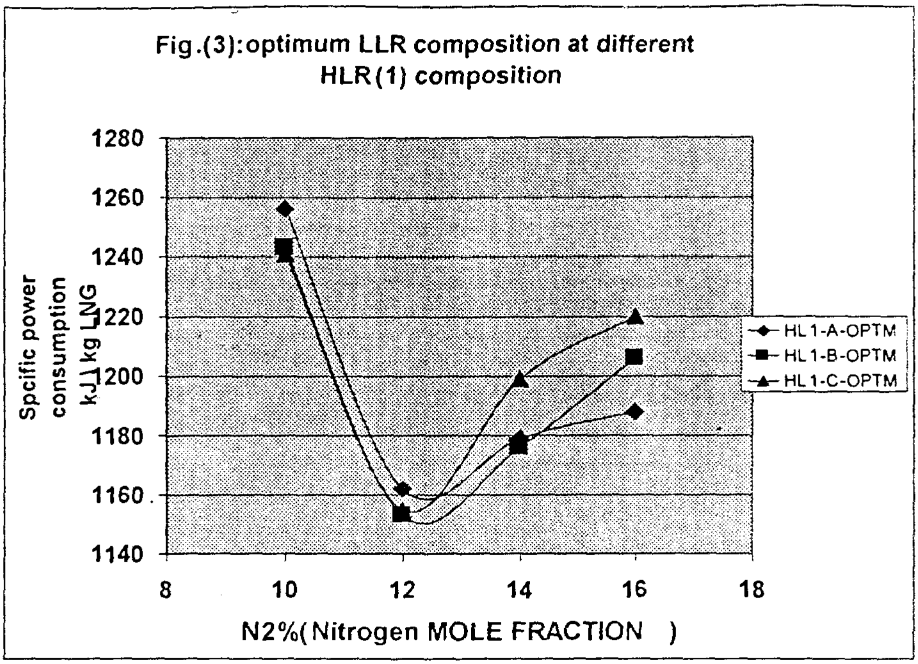

Fig.(3):optimum LLR composition at different HLR(1) composition

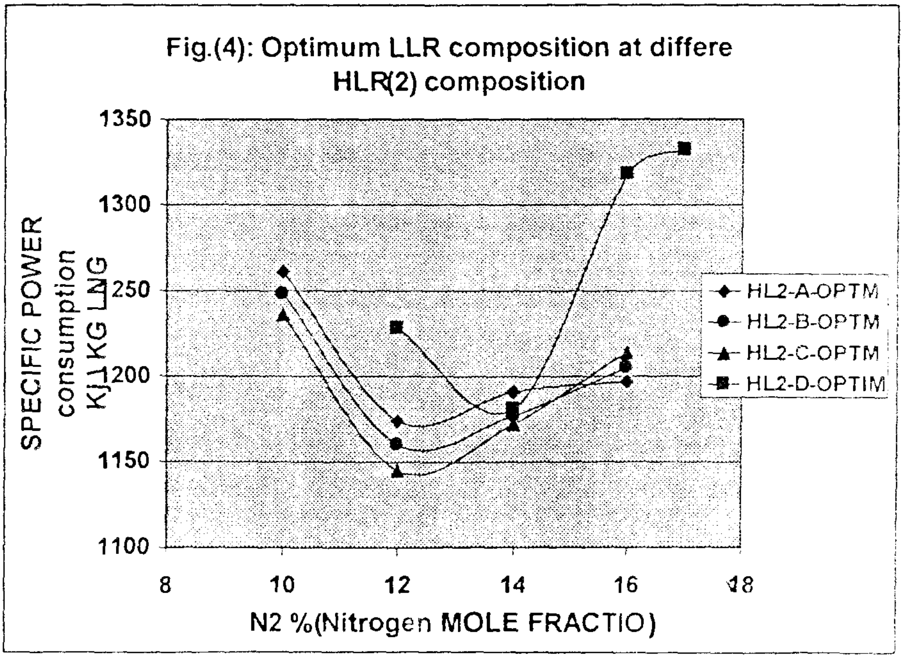

Fig.(4): Optimum LLR composition at differe HLR(2) composition

Fig.(5) : Optimum LLR composition at different HLR(3) composition

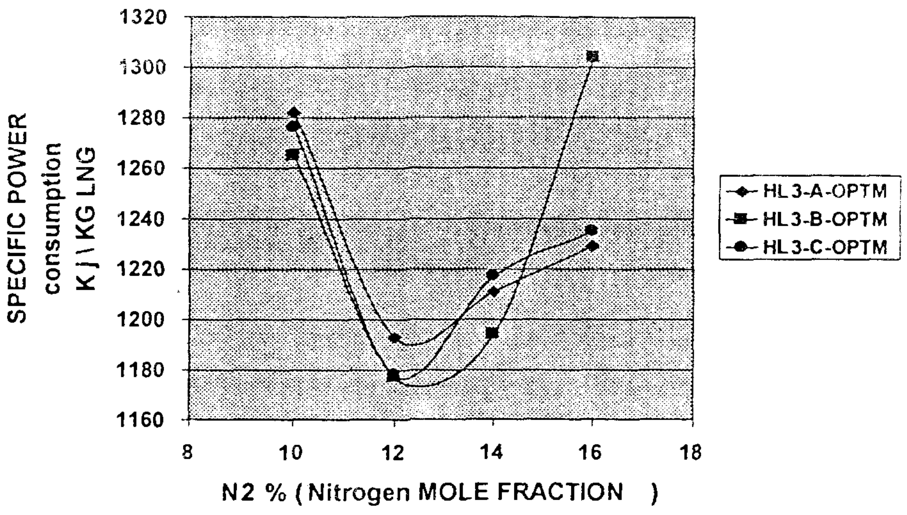

Fig.(6)Optimum condition for the DMRC process

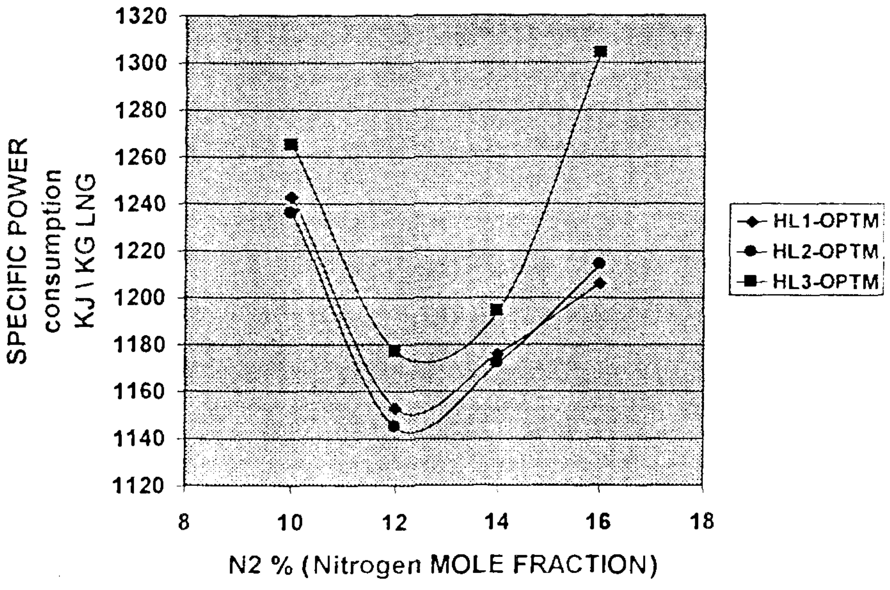

FIG.(7): Influence of the temperature of cooling water on different cost items for theDMRC process at optimum conditions (HL2-C-35-12)

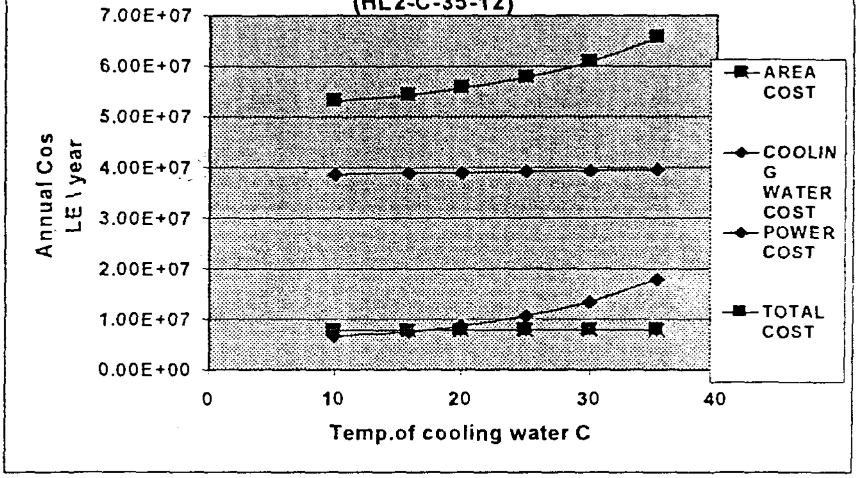

Figure (8)Comparison of the specific power requirments with that of existing liquefaction plants