IMPROVING ENERGY EFFICIENCY OF LNG PLANTS

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Plant owners have historically preferred robust and dependable facilities rather than very efficient process with more stringent operating constraints.

In today environment, improving energy efficiency of LNG Plants is a major focus for Operators.

Main factors contributing to this shift toward enhancing efficiency are:
- Higher price of feed gas/sales gas
- Reduction of feed gas supply in some LNG Plants
- Worldwide pressure to reduce the GHG footprint of industrial facilities
- Actual or potential CO_2 taxes

The paper will first review various options to increase the energy efficiency for a brand new plant for a given liquefaction process. Among the various options scrutinised:
- Heat recovery options (combined cycle and others)
- Large Frame or aero-derivative driver for refrigerant compressors or power generator.
- Electric drivers for refrigerant compressors or E -LNG.
- Heat absorption systems / chilled water loop duty
- Cooling of Gas turbine Air inlet
- Combination of the above.

Expected efficiency enhancement is evaluated and a 30 % improvement compared to robust and simple LNG facilities can be achieved.

For existing facilities some practical energy efficiency improvement can be implemented as well.
As an example, the second part of the paper will present a revamping of an existing LNG facility making use of heat absorption systems.
The criteria for selection as well as the expected improvement will be summarised together with some project implementation and operating aspects.

BIO

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1. INTRODUCTION

Since its inception in the 60's, LNG industry energy efficiency has improved mainly driven by the type and size of main refrigeration drivers (initially steam turbine then gas turbine of increasing power and/or efficiencies).

Few LNG plants though feature high level of heat integration and the projects for revamping / debottlenecking of these facilities focus more on increasing the throughput than improving the energy efficiency of the facilities.

Is it possible to design new plants with better energy efficiency and lower cost?

Can the debottlenecking of existing facilities achieve both throughput increase and improved energy efficiency?

2. LNG LIQUEFACTION FACILITIES GHG EMISSIONS

The volume of Greenhouse Gas emissions emitted to the atmosphere for each tonne of LNG produced provides a recognised benchmark to assess greenhouse emissions intensity of an LNG Plant.

This metric is not a direct reflection of the energy efficiency which can be influenced by gas composition (HC and impurities) and ambient conditions.

However, an order of magnitude of the global CO_2 released by the liquefaction Plants would provide some rule of thumb of what can be achieved by improving the thermal efficiency of LNG plants.

In 2008, about 22 % of the worldwide LNG producing capacity is designed with steam driven refrigeration compressors with low efficiency, while 40 % of the overall capacity have been commissioned in the last 6 years or so. Latest LNG facilities are significantly more efficient than older trains.[20]
Without taking into account the native CO_2, a fair estimate based on internal data and published data [1] would average to 0, 4 Millions tons of CO_{2equ} per Million ton of LNG (around 45 kg of CO_2/boe.).

More detailed information can be found in [13] for a Nigerian LNG facility.

The latest IGU report quoted some 174 Millions of LNG produced in 2008.

Hence a guess-estimate of the overall $CO_{2\ equ}$ emissions for the LNG liquefaction plants in 2008 are about **70 Millions tons of CO_2 equivalent.**

This can be compared to the OGP(Intl association of Oil and Gas Producers) 2007 figures of 0.076 Millions tons of CO_{2equ} per Million ton of production of field hydrocarbon for Europe selected as a area without continuous flaring; OGP figure includes native CO_2 released to atmosphere.

The emissions from LNG facilities can be curtailed thanks to a joint effort of the major producers to develop more efficient new projects but also to revamp the existing facilities.

3. OPTIONS TO IMPROVE THE LNG PLANT'S ENERGY EFFICIENCY

There are a great number of possible options to improve the energy efficiency.

Among the main options we can list:

3.1 Architecture

- Optimum pressure of natural feed gas (+ 0,7 % LNG production for a 1 bar increase of the feed gas pressure) [6]
- Cooling medium (Sea water vs. Air Cooling) : each degree of cooling media translates into approximatively in 1 % extra power for the same production
- Optimized lay-out to reduce heat-in-leak in cryogenic piping
- Reduction of flaring (For example recompression of ship loading boil-off-gas)[12]
- N2 purge of flare header vs. flare pilots

3.2 Process & Engineering

- Optimum design of the pre-treatment section (reduction of heat input for regenerating Acid Gas removal solvent)
- NGL recovery optimisation [13]
- Lower Pressure drops specially for the low pressure refrigerant circuit [13]
- Selection of liquefaction process although other consideration than the theoretical efficiency of the process can be prevailing criteria (robustness, EPC competition,) [3] and [2].
- Use of liquid expanders which alone improve significantly the efficiency of the process and can be used on all processes. (around 2 % for a C3 MR process licensed by APCI)

3.3 Equipment

- Optimum design of Refrigerant condenser and sub-cooler.[6]
- For a given process, reduced temperature approach on chillers by increasing active heat exchange surface (as proposed by TECHNIP/WIELAND) [7]
- Enhanced heat insulation to reduce heat-in leak
- Higher efficiency of compressors consistent with expected robustness.
- Choice of the various gas turbine drivers with the aim to improve the heat rate:
    - large turbine
    - aeroderivative gas turbine versus industrial frame

Basically the larger the frame, the more efficient the turbine.

Aeroderivative gas turbine exhibits significant higher efficiency see TABLE 1

LM 2500 + are used on DARWIN LNG [10]&[11].

Turbine	Shaft	ISO Power (kW)	Efficiency	Fuel Consumption (Indexed)	Scheduled Downtime
Frame 5D	Dual	32,580	29.4%	100	2.6%
LM2500+	Dual	31,364	41.1%	72	1.6%
LM6000	Dual	44,740	42.6%	69	1.6%
Frame 7E	Single	86,225	33.0%	89	4.4%
Frame 9E	Single	130,100	34.6%	85	4.6%

Table 1: Typical Efficiency of Gas Turbine

- E-LNG concept and electrical drivers [9] as installed on SNOVHIT.

- Air evaporation [11] or air chilling at the Gas turbine air inlet: reducing air inlet temperature marginally improves the efficiency while increasing available power in tropical locations [8]. (for an LM 6000 the efficiency between air temperature of 35 deg.C and 15 deg.C increases by 7% in relative terms).

- Ultra Super Critical Steam(USC Steam) system as developed in latest power plant design[17]

3.4 Heat Recovery

Heat recovery at the exhaust of the gas turbine [16]; recovered thermal energy which can be used in the various combination of :

- Co generation of heating media to meet process duties requirement and motive steam driving process steam drivers.
- Combined Cycle : power generation thru steam turbine driving electrical generators
- Heating media for heat driven absorption units

3.5 Operation

Optimum operating parameters supported by an Advanced Process Control system (this option is more and more applied and reported cost benefits are straightforward in terms of a better utilisation of train capacity and smoother operation leading to a better efficiency [5])

While the newest LNG plants such as QATARGAS II make use of some of the solutions listed above, none uses heat driven absorption package to directly convert recovered waste heat into an additional cooling cycle (chilled water) that could be used in the process area as well as in the gas turbine air inlet for example.

4. HEAT DRIVEN ABSORPTION CHILLERS

A Heat Driven Absorption Chiller is a cooling machine using thermal energy (steam, hot water) instead of mechanical compressors consuming electricity or valuable fuel gas.
The most common working fluid pair is composed of water and Lithium Bromide, a non toxic and stable salt instead of troublesome fluids (CFC or ammonia).
A general scheme is provided in figure 1

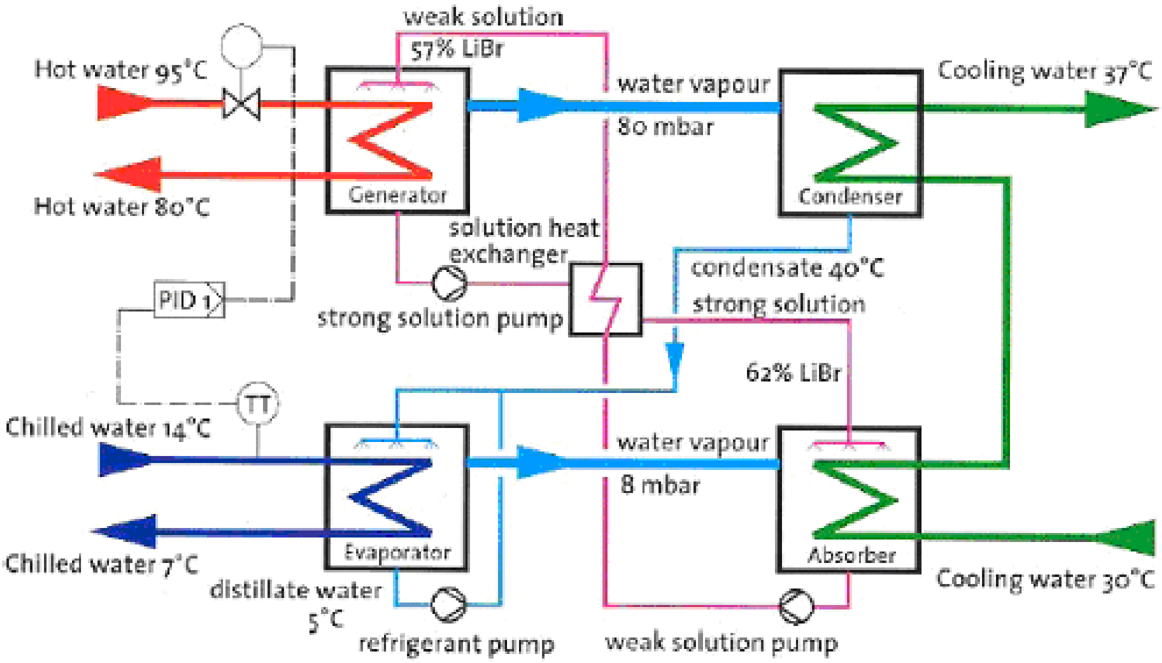

Figure 1: Heat driven Absorption Chiller (courtesy of Veolia)

Absorption systems are widely used for air conditioning mainly in South East Asia and US.

Industrial applications are fewer but still some hundred units are installed in Oil & Gas, Refineries or Petrochemical facilities.

The main benefits of Heat Driven Absorption machine is to make use of low level thermal energy otherwise cooled by external cooling media or release to atmosphere.

Using LiBr based absorption system in a new plant or for a revamping doesn’t increase the level risk as opposed to Ammonia.

In hot climate conditions a chilled water loop (7deg.C) can be used to cool down process fluid lower that available ambient temperature cooling media.
Conversely, cold climate limits the benefits of typical Absorption Chillers.

Several suppliers can provide large packages (superior to 15 MWth) than can be adapted to local conditions.

The operation of absorption chillers is easy with a limited number of small pumps and trouble-free static equipment. However corrosion if not considered with care can be detrimental to the availability of the chillers.

All the above characteristics are winning advantages for a successful integration in a LNG Plant.

Many patents have been applied to use absorption chillers to lower the air inlet temperature to gas turbine.
However few patents focus on the use of the absorption refrigeration cycle for gas liquefaction [14], [15].

5. STUDY CASE FOR NEW PLANT

To further investigate the benefits of Heat Driven Absorption units, TOTAL with the support of a specialised engineering contractor launched a study to integrate absorption chillers in typical LNG Plant.

A base case without heat integration is compared against two cases with heat integration:

- Heat Recovery Steam Generator (HRSG) raising HP stream driving back pressure steam turbine process compressors and/or generator.
- Absorption chillers driven by steam raised HRSG located at the exhaust of Gas Turbine

Process heat requirement for both cases with HRSG is covered by co-generated and/or letdown steam.

The comparative study is based on a well known C3MR APCI process with upstream NGL recovery CRYOMAX in a tropical / warm environment.

To simplify the comparison, the study is only based on the liquefaction process downstream the NGL recovery.

Three cases (with different production levels and different main refrigeration drivers) have been defined as follow:

- Two FRAME 7 with 20 MW helper/booster each for one train; required power is supplied by FRAME 6's
- Two FRAME 9 with 23 MW starter each for one train ; required power is supplied by FRAME 6's
- E-LNG : Electric motors on main refrigeration drivers associated to a power plant based on TRENT 60 WLE (some 6 TRENT are foreseen for one process train)

The duty of the chilled water closed loop produced by the absorption units encompasses:

- Gas turbine air inlet cooling
- Sub-cooling Propane refrigerant
- Pre-cooling the feed gas and the MR refrigerant instead of propane cooling service

All utilities requirement (power, heat and cooling media) have been estimated for all cases.

As a result, for a base case without heat recovery (base 100) the specific energy consumption of the various cases with heat recovery schemes are given in the TABLE 2

	Combined Cycle	Absorption Chillers
2 frame 7	91%	89%
2 frame 9	83%	83%
El Motor (trent 60 Genset)	76%	69%

Table 2: Liquefaction Process Specific Energy Consumption

NOTE: For E-LNG case, the combined cycle option is not considered the heat is recovered to meet process duty only

Additionally, absorption chillers can boost the production potential of LNG trains when compared with combined cycle

	POTENTIAL PRODUCTION
2 FRAME 7	22%
EL MOTOR (TRENT 60 GENSET)	26%

Table 3: Potential Additional Production for a Given Refrigeration Power Duty

This production improvement partly comes from the improvement of specific energy, partly from enhanced available power (cooler air feeding the gas turbine)

Taking into account the simplistic hypothesis of the study, we can draw the following conclusions:

- **The absorption chillers compared well with Combined cycle in terms of energy efficiency** and can be used in conjunction with Combined Cycle
- There is a good match in terms of heat level between heat recovered at the exhaust of aeroderivative gas turbine and the heat requirement of absorption chillers.
- **The efficiency of the liquefaction part of the process can be improved by some 30% when combining E LNG with aeroderivative gas turbine and absorption chillers** when compared to a base case without heat integration
- However given the limited size of current available aeroderivative gas turbine, the required number of generators can be high for large LNG Plants
- **In all cases, use of absorption chillers increases the potential capacity** of the liquefaction process for a given refrigeration power duty.

6. REVAMPING OF AN EXISTING FACILITY

For an existing plant, options to improve the efficiency are more limited than for a grassroot project.

Limitations can be:
- existing equipment: drivers (refrigeration, power generation), steam boilers…
- various existing process limitations
- supply of cooling media
- lay out limitation such as open access to gas turbine exhaust
- short time to implement process modification without impact on production
- availability of gas supply
- local requirement (power to third parties)

When taking all the above constraints into account, TOTAL has launch a study on an existing LNG facility to combine moderate production increase and improved efficiency.

The project in reference is a two train's facility located in a warm climate country

It is based on:
- APCI C3 MR Process,
- 2 Frame 7 with starter per train
- Power generation by four FRAME 5
- Heating media provided by stand-alone by LP steam boilers.
- Cooling medium is sea water and the temperature of rejected sea water is tightly controlled.

The energy losses for the reference project are about 67 % (POWER GEN and REFRIGERATION COMPRESSOR DRIVERS exhaust) of the energy provided by fuel gas see TABLE 4

USED 33%	ELECTRICITY	4%
	THERMAL	5%
	MECHANICAL	24%
LOST 67%	POWER GEN EXHAUST	14%
	C3/MR FRAME 7 EXHAUST	53%

Table 4: Energy Balance

The engineering work focused on:
- develop tailor made absorption chillers (usually design as standard package) to the site specifics (cooling medium operating conditions, steam temperature level…)
- optimisation of the various possible cooling duties and chilled water temperature
- process modifications such as flashing liquid expanders on MR and LNG
- coarse checking of hydraulic capacity of process units
- detailed review of compressor curves and margin based on compressor tests
- integration of the above options
- lay-out, schedule and cost estimate of the various cases.

Four cases with increasing levels of heat integration were defined as summarised in Table 5.

	CASE A	CASE B	CASE C	CASE D
LIQUID EXPANDER	Y	Y	Y	Y
CONVERSION STARTER-->HELPER		Y	Y	Y
HRSG		Y	Y	Y
BACK PRESS STM GENERATOR		Y	Y	Y
ABSORPTION CHILLER			Y	Y
FRAME 7 AIR INLET COOLING			Y	Y
FEED GAS PRE-COOLING				Y
LNG PRODUCTION INCREASE	**4%**	**7%**	**7%**	**9%**
SPECIFIC ENERGY CONSUMPTION	**-2%**	**-9%**	**-9%**	**-6,50%**

Table 5: Study Cases Additional Production and Specific Energy Consumption

As can be inferred from the above results, targets in terms of additional production and efficiency improvement are limited.

Difficult access for recovering exhaust heat from main refrigeration compressors gas turbine (accounting for 53 % of the energy input) due to compact lay-out within the train is the main reason for this modest efficiency improvement.

However all cases shows relatively low specific cost ($/mtpa) as pictured in Table 6 which compared favourably with current LNG project cost per unit capacity

	CASE A	CASE B	CASE C	CASE D
$09/LNG tpa	200	350	430	430

Table 6: Marginal Capex Ratio

The potential for improving energy efficiency depends very much on original design. Hat Recovery System from gas turbine exhaust should be adapted to smaller footprint to meet lay-out constraints.

When applying Case D modifications, the **percentage of used energy increases from 33% to 38 %.**

7. CONCLUSIONS

Thermal efficiency improvement for LNG plants is an ongoing trend with more new grass-root projects featuring various degrees of heat integration towards a long term quest up to the zero CO_2 LNG facility as described by KIKKAWA San[19].

TOTAL will be part of this effort for the entire LNG chain and for the O&G business in general (refer to Anne Rocher (TOTAL) presentation [18]); this effort will be exemplified in the design of ICHTHYS and STHOCKMAN LNG Plants featuring both comprehensive heat integration options.

Future projects could make use of absorption chillers as part of heat integration systems; energy efficiency improvement with combined cycle or heat driven absorption chillers are comparable. Most favourable case being E-LNG based on aero-derivatives gas turbines associated to heat driven absorption chillers in tropical area.
Absorption chillers require only low pressure steam and are less complex than combined cycle powered by high pressure steam.

Enhancing the energy efficiency of existing LNG facilities is also a robust business case when associated with additional potential production to pay for the modification project. However practical improvement of the thermal efficiency is depending on original design features of the facility such as lay-out or choice of refrigeration drivers.

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