Technical and Economic Study of a Fuel Gas Turbo Compressor at the Gas Complex Plants

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Abstract
As part of the strategic objective of developing natural gas resources mainly from the HASSI R'MEL field in southern Algeria, LNG plants have been built in the north of the country, whose main purpose is the export of LNG to Europe by LNG carriers, among these plants, we cite the LNG complex which contains strategic and auxiliary equipment designed and built to achieve a given performance and a required function, the latter is to provide energy to the fluid, allowing it to be transported in pipes and overcome the resistance to movement. On the industrial level, a better understanding of the static and dynamic behavior of equipment is essential both for predicting operating conditions and for estimating service life. A machine under study must meet various requirements relating to its productivity, operation, safety, longevity, and maintenance costs. It is the role of maintenance in the broadest sense of the term to ensure the normal operation of these machines throughout their entire lifespan. Traditional maintenance methods are limited to operating the machines until they break down, or to carrying out maintenance at fixed intervals without taking into account the time, cost, quality of repair and even the HSE point of view. For example, on the LNG complex units, where it is necessary to supply the boiler with fuel gas instead of natural gas at a specific pressure and flow rate, a turbocharger was used, on which our technical and economic study is based.
Keywords: Fuel gas, Self-consumption, Cost of maintenance, Availability rate, Charge rate.

INTRODUCTION

Industrial maintenance, which aims to ensure the proper functioning of production equipment, is a strategic function in companies. It is closely linked to constant technological development, the emergence of new management methods, and the need to reduce production costs [1]. The LNG liquefaction process used in LNG complex units requires the production of water vapor to drive the turbo-machines. The mobilization of these turbo-machines requires the establishment of an adequate maintenance policy, because the unavailability of one or more pieces of equipment causes a partial or total shutdown of the unit; which affects the unit's efficiency from an economic point of view. The fuel used to feed the boiler producing the superheated steam consists of natural gas, high pressure fuel gas at 3.5 bars effective (pressure by which the fuel gas is spontaneously admitted into the boiler burners), low pressure fuel gas at 1.1 bars effective (insufficient pressure to supply the boiler, which requires an increase in pressure to 3.5 bars effective via a fuel gas turbo-compressor) [2], [3]. The importance of the Turbocharger is the reduction of self-consumption rate of natural gas by recovering the total quantity of low pressure fuel gas, which will be flared if this turbocharger is broken down. Our technical-economic study is based on the comparison between the estimated maintenance costs of this turbocharger and the loss of earnings during one year in the event of its immobilization [3] and to achieve the objective of our work we take into consideration the self-consumption on a liquefaction train which is the sum of two types of consumption; a minimum consumption required for operation and depends solely on the design implemented by the manufacturer and the other an overconsumption which is dependent on the degree of maintenance applied and the know-how of the operator.

THE TECHNICAL PART

Etymologically, the term "maintenance" comes from the Latin manuteneure (from manu, hand, and tiente, to hold) and referred to the action of keeping combat-tested military troops in good condition. Since then, its meaning has evolved, and maintenance activities now have a more technical and much more general connotation.
According to the **AFNOR X60-010** standard, maintenance is defined as "all actions that maintain or restore an asset in a specified condition or capable of providing a specific service." Maintaining therefore means carrying out operations (cleaning, greasing, inspection, repair, overhaul, improvement, etc.) which allow the potential of the equipment to be preserved to ensure continuity and quality of production. As well as choosing the means to prevent, correct or renovate depending on the use of equipment [4], [5].
The maintenance mindset is to control interventions.
The goals of maintenance are:

- Maintaining machine capital;
- Eliminating production downtime and disruptions (guaranteeing delivery capacity);
- Improving safety and protecting the environment.

Maintenance Strategies

In the industrial environment, three types of maintenance are distinguished:

- Corrective maintenance;
- Systematic preventive maintenance;

Condition-based preventive maintenance

Corrective *maintenance*

According to the **AFNOR X60-010** standard, corrective maintenance is defined as "maintenance performed after failure." In this approach, machines operate without any special maintenance or monitoring costs until an incident occurs. In corrective maintenance, any incident on the machine has an impact on operations, and because shutdowns occur randomly, planning in production is difficult, if not impossible.

Systematic preventive maintenance

According to the **AFNOR X60-010** standard, systematic maintenance is defined as "maintenance carried out according to predetermined criteria with the aim of reducing the probability of failure of an asset". Systematic preventive maintenance is the set of systematic visits carried out preventively, prepared and scheduled before the probable date of occurrence of a failure. Waiting for the machine to break down to repair it seems to be the worst solution, which is why some users choose periodic systematic maintenance, but this method does not take into account the conditions of use or assembly. Because most of the time; elements are replaced when they would still be usable or damaged components are repaired too late.

Conditional preventive maintenance

According to the **AFNOR X60-010** standard, conditional maintenance is defined as "preventive maintenance subject to a predetermined type of event (self-diagnosis, information from a sensor, measurement of wear) revealing the state of deterioration of the asset". Conditional maintenance is synonymous with "as-is" or predictive maintenance, a term reserved for use with rotating machines. This form of maintenance ensures

continuous monitoring of equipment in service with the aim of preventing expected failures [4], [5].
Conditional maintenance is linked to the condition of the machine:

- Component to be replaced only if tolerances are reached, etc;
- Machine to be stopped only if its condition requires it;
- Rotor to be balanced if tolerances are reached.

THE FUNCTIONS OF A MAINTENANCE SERVICE

Function method

This function is considered the brains of the maintenance department, defining:

- What needs to be done, with whom, and how;
- Intervention methods and techniques;
- Maintenance resources and standards;
- Creation and use of technical and historical documentation;
- Development of maintenance methods.

It determines the necessary resources (material and human) and the frequencies of intervention.

Scheduling function

This function brings together the resources and materials to make the work to be carried out executable, it establishes the work schedule, monitors its progress and ensures that deadlines are met; it defines labor requirements, controls and gathers information relating to the work,

Function of the preparation

Although arising from the methods function, work preparation determines the process of the different phases, the necessary means, the operating times and the preparation of the workforce,

Launch function

Ensures the distribution of work according to a schedule established according to the load and ensures the management and direction of men for the proper execution of the work; She is responsible for the supervision and orientation of staff.

Execution Function

This is the operational function of maintenance; it ensures the restarting of machines by carrying out interventions. It guarantees the required level of quality within the planned timeframes, on the fixed date and in the best safety conditions.

Function of inventory management

The first task is to forecast the plant's ongoing needs for routine maintenance inventory items and spare parts specific to production facilities.
This determines the quantities to be restocked based on inventory levels, consumption, and delivery times.

Function of cost management

Maintenance services can increase the company's profitability by reducing costs.
To manage these costs, it's essential to understand maintenance costs.

MAINTENANCE OF THE STEAM TURBINE INSTALLATION

The technical facilities owned by the GAZ region represent a significant investment capital; this capital must be preserved and managed efficiently. The maintenance division requires a wide range of skills in various fields, which leads to the organization of maintenance around four departments: turbo machinery, electrical, instrumentation, and industrial mechanics. A preventive maintenance program is a primary necessity to ensure the proper management of steam turbine-driven facilities; forced shutdowns of the facility must be minimized.

To this end, we can classify turbine inspections into three types:

CONDITIONAL MAINTENANCE (OPERATIONAL INSPECTION)

These include the sum of observations made during unit operation. Operational data must be recorded to assess equipment performance, maintenance needs, and intervention when these readings indicate alarms that subsequently triggered the turbine. The most important are:

- Turbine rotor vibrations,
- Steam temperature,
- Lubricating oil temperature,
- Turbine speed,
- Steam flow rate.

SYSTEMATIC MAINTENANCE (SCHEDULED INSPECTIONS)

➢ ***Inspection V2***

This inspection is performed while the facility is running (without shutting down the system). It involves walkthroughs and visual inspections of the various equipment, with the aim of checking for:

- Leaks;
- Vibrations and axial displacement;
- Abnormal noise;
- Excessive heating, etc.

➢ ***Inspection V3 (At a standstill)***

Vital parts, such as bearings, main and auxiliary oil pumps, quick-closing and regulating valves, should be serviced more frequently, i.e. every 1-2 years. A V3 preventive inspection of the turbo-compressor is carried out as follows:

- Removing the front and rear bearing caps,
- Using the lifting crane to remove the front and rear bearings;
- Cleaning and glazing the shaft tang;
- Checking the radial clearances of the bearings;
- Reassembling the bearings;
- Checking the clearances at the oil deflectors on the bearings and on the thrust bearing;
- Checking the condition of the thrust pads, glazing, and reassembling;
- Reassembling the pulse take-offs on the load bearings;
- Installing the bearing caps;
- Connecting the temperature and vibration measuring devices by the instrument technicians;
- Restarting the lubrication system;
- Control of control components (scraper valve and inlet valves, static pressure gauge and pressure limiter);
- Cleaning of oil tanks, filters, oil cooler, flushing of the lubrication oil circuit, and adjustment;
- Post-overhaul testing (technical).

MAINTENANCE COST ESTIMATE (V2 & V3)

To estimate the cost of maintenance (V2 & V3) we developed repair operating ranges from which we identify the tasks, timescales and resources required for each intervention. Our calculation is based on the hourly cost of each operator and the total cost of the spare part.

Fig. 1. LNG liquefaction refrigeration compressor [6]

The results obtained are represented in the schedules and tables below [7]:

Schedule 1. Work schedule V2 Steam Turbine

Item	Designation	Age	Hour	Month Week 01 S M T W T
01	Turbine Control Side Removal	4	3H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
02	Removing the Front Turbine Bearing (Disconnect, 4 Bolts)	4	1H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
03	Removal of Bearing and Thrust Bearing	4	1H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
04	Removing the Rear Turbine Bearing	4	1H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
05	Cleaning the Joint Plane (Front and Rear Bearings)	4	2H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables

06	Bearing and Thrust Clearance Checks	4	8H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
07	Reassembly of Accessories	4	4H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
08	Restoration of the premises	1	4H	1 Maneuver

Schedule 2. Work schedule V2 Fuel Gas Compressor

Item	Designation	Age	Hour	Month Week 01 S | M | T | W | T
01	Removing the Front and Rear Bearings of the Compressor	4	8H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
02	Cleaning and Control	4	8H	1 Mechanical Engineer+1 Agains[illegible]er + 2 TS Mechanical Tools + Consumables
03	Cleaning the Bearings	4	2H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
04	Reassembly of the Bearings	4	1H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
05	Adjusting the Stop Clearances	4	4H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
06	Closing of the Bearings	4	8H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical

				Tools + Consumables
07	Restoration of the premises	1	4H	1 Maneuver

Schedule 3. Work schedule V3 Steam Turbine

Item	Designation	Age	Hour	Week 01
				S | M | T | W | T | F | S
01	Turbine De-Insulation & Removal of Front Turbine Bearing Accessories	4	8H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
02	Removal of Turbine Control and Regulator Side	4	8H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
03	Removing the Turbine Cylinder	4	8H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
04	Removing the Rear Bearing and Coupling Cap	4	2H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
05	Removal of the Regulating Valve & Removal of the Stop Valve	4	4H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
06	Cleaning the whole & Rotor Visual Inspection	4	9H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
07	Geometric Self-Check, Bearing Check & Stop-Valve Check	4	4H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
08	Checking the Regulating Valve + Reassembling the Assembly (Turbine)	4	8H	1 Mechanical Engineer+1 Against Mete[illegible] Mechanical Tools + Consumables
09	Restoration of the premises	1	4H	1 Maneuver

Schedule 4. Work schedule V3 Fuel Gas Compressor

Item	Designation	Age	Hour	Week 01							Week 02						
				S	M	T	W	T	F	S	S	M	T	W	T	F	S

01	Removal of Communication Piping (Suction and Discharge)	4	12H	1 Mechanical Engineer +1Against Meter + 2 TS Boiler +2 TS Instrumentation Tools + Consumables
02	Removal of the Front and Rear Bearing Caps & Removal of the Compressor Cylinder	4	8H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
03	Cylinder Handling (Upper Part) & Cylinder Reversal	5	5H	1 Mechanical Engineer +1Against Meter + + 2 TS Mechanical +Crane Operator Tools + Consumables + Crane
04	Removing the Front, Rear Bearings and Compressor Rotor	4	2H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
05	Checking and Controlling Clearances (Bearings, Sealing, Gas Oil Sealing, etc.) & Cleaning the Compressor	4	16H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
06	Reassembly of the Half Bearings with Rotor & Checking of Clearances (Thrust Bearing Clearances, Bearings, Stages,etc)	4	16H	1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
07	Adjustment of axial clearances,	5	8H	1 Mechanical Engineer +1Against Meter + + 2 TS Mechanical +Crane Operator

	thrust bearings and bearings & blowing, cleaning and installation of the cylinder				Tools + Consumables+ Crane
08	Tightening the Joint Plane & Mounting the Compressor Suction and Discharge	4	24H		1 Mechanical Engineer+1 Against Meter + 2 TS Mechanical Tools + Consumables
09	Place the Instruments + Restore the Site	4	4H		1 Mechanical Engineer ++2 TS Instrumentation + Maneuver Tools + Consumables

Table 2. The cost of V2 maintenance of the steam turbine

Human Resources	Unit	Quantity	Unit Price DA	Hours	Amount in DA
Mechanical Engineer	Man/hour	1	700,50	20	14 010,00
Against Meter	Man/hour	1	623,40	20	12 468,00
Mechanical Technician	Man/hour	2	568,20	40	22 728,00
Maneuver	Man/hour	1	307,20	2	614,40
Total M.H				82	49 820,40
Material Means	Unit	Quantity		Price	Amount in DA
Consumables	Package	Package		40 000,00	40 000,00
Total M.M					40 000,00
Grand Total					89 820,40

Table 2. The cost of V2 maintenance of the fuel gas compressor

Human Resources	Unit	Quantity	Unit Price DA	Hours	Amount in DA
Mechanical Engineer	Man/hour	1	700,50	31	21 715,50
Against Meter	Man/hour	1	623,40	31	19 325,40
Mechanical Technician	Man/hour	2	568,20	62	35 228,40
Maneuver	Man/hour	1	307,20	1	307,20

Total M.H			125	76 576,50
Material Means	Unit	Quantity	Price	Amount in DA
Consumables	Package	Package	40 000,00	40 000,00
Total M.M				40 000,00
Grand Total				116 576,50

Table 3. The cost of V3 maintenance of the steam turbine

Human Resources	Unit	Quantity	Unit Price DA	Normal Hours	Amount in DA	Hours at 50%	Unit Price DA	Amount in DA	Hours at 75%	Unit Price DA	Amount in DA	Hours at 100%	Unit Price DA	Amount in DA	
Mechanical Engineer	Man /hour	1	700,50	39	27 319,50	4	1 050,75	4 203,00	4	1 225,88	4 903,50	5	1 401,00	7 005,00	
Against Meter	Man /hour	1	623,40	39	24 312,60	4	935,10	3 740,40	4	1 090,95	4 363,80	5	1 246,80	6 234,00	
Mechanical Technician	Man /hour	2	568,20	78	44 319,60	8	852,30	6 818,40	8	994,35	7 954,80	10	1 136,40	11 364,00	
Maneuver	Man /hour	1	307,20	2	614,40	1	460,80	460,80	0	537,60	0,00	0	614,40	0,00	
Total M.H				158	96 566,10	17		15 222,60	16		17 222,10	20	4 398,60	24 603,00	
Material Means	Unit	Quantity		Price	Amount in DA										Grand Total
Consumables	Package	Package		40 000,00	40 000,00										

Total M.M	40 000,00							
Grand Total	136 566,10		15 222,60		17 222,10		24 603,00	193 613,80

st of V3 maintenance of the fuel gas compressor

(cut off)	Unit	Quantity	Unit Price DA	Normal Hours	Amount in DA	Hours at 50%	Unit Price DA	Amount in DA	Hours at 75%	Unit Price DA	Amount in DA	Hours at 100%	Unit Price DA	A i
	Man/hour	1	700,50	83	58 141,50	8	1 050,75	8 406,00	8	1 225,88	9 807,00	16	1 401,00	2 4
	Man/hour	1	623,40	83	51 742,20	8	935,10	7 480,80	8	1 090,95	8 727,60	16	1 246,80	1 9
	Man/hour	2	568,20	118	67 047,60	16	852,30	13 636,80	16	994,35	15 909,60	32	1 136,40	3 3
ı	Man/hour	2	568,20	16	9 091,20									
	Man/hour	2	568,20	32	18 182,40									
	Man/hour	1	402,52	1	402,52									
	Man/hour	1	307,20	2	614,40	1	460,80	460,80	0	537,60	0,00	0	614,40	(
				286	177 545,70	33		29 984,40	32		34 444,20	64	4 398,60	7 7
	Unit	Quantity		Price	Amount in DA									
	Hours	1	12 000,00	9	108 000,00									
	Package	Package		40 000,00	40 000,00									
					148 000,00									
					325 545,70			29 984,40			34 444,20			7 7

Table 5. Maintenance Summary

Cost of V2 maintenance of the steam turbine	89 820,40 DA
Cost of V2 maintenance of fuel Gas Compressor	116 576,50 DA

Cost of V3 maintenance of the steam turbine	193 613,80 DA
Cost of V3 maintenance of fuel Gas Compressor	468 703,90 DA
Cost of Spare Parts (V2 & V3)	5 000 000,00 DA
Total Cost Maintenance	5 868 714,60 DA

ECONOMIC STUDY

Recently commissioned LNG plants operate with self-consumption rates of less than 2%, and much effort is being made to further reduce this rate in order to improve the thermal efficiency of these plants, the cost price of LNG and limit greenhouse gas emissions (mainly CO_2 produced by the combustion of gas in boilers and by the burning of flared gases). The operating performance of a liquefaction plant is assessed according to two main criteria:

✓ Quantitative criterion: **Availability rate** (depends on the degree of maintenance applied); **Load rate which** determines the quantity of energy produced (depends on the pipes and performance of the equipment).

✓ Qualitative criterion: **Self-consumption**, specifications, costs, self-consumption is the image of the thermal efficiency of the plant, and it is also the reflection of the know-how of the operator.

$$\text{Availability Rate} = \frac{\text{Operating Time} \times 100}{\text{Design Operating Time}} \quad (1)$$

$$\text{Charge Rate} = \frac{\text{Actual Production} \times 100}{\text{Design Production}} \quad (2)$$

Self-consumption: energy consumed or lost for the liquefaction and transformation of natural gas.

Reminder of self-consumption

Natural gas undergoes several processes before being transformed into finished products. These processes require the consumption of a portion of the incoming energy in the form of fuel in the boilers, while another portion of the energy is consumed to compensate for losses through evaporation or product leaks.

Self-consumption is the amount of energy consumed or lost in the transformation of natural gas (NG) into finished products:

(LNG- Ethane, Butane, Propane, Light Naphta C5+)

Self-consumption Formula:

$$AC\% = \frac{a - b}{a} x10 \quad (3)$$

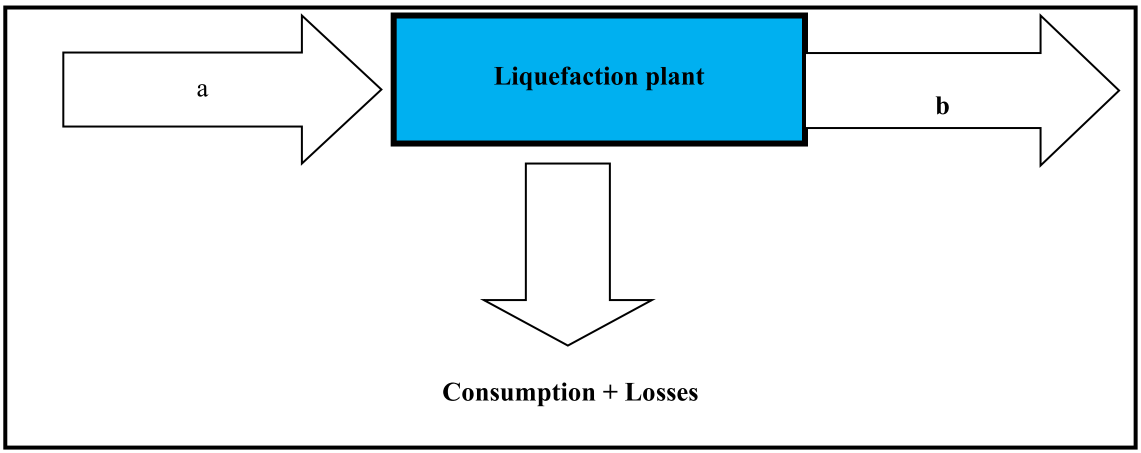

Fig. 2. Gas complex liquefaction schema

: Incoming energy (contained in natural gas);
b: Outgoing energy (LNG, C2, C3, C4, C5+ marketed);
b /a : Represents thermal efficiency.
Data interpretation Comparative method to achieve the objective of this work we have the following tables [8]:

Table 6. Temperature LNG

Temperature	Turbo-compressor Stopped	Turbo-compressor in service (Speed 6500 Tr/min)
T° of LNG [C°]	-157,5 C°	-159 C°

Analysis of table 06

- Note that the temperature of LNG during turbo-compressor operation is two degrees lower than when stopped, which has a positive effect on the efficiency of the entire unit;
- The storage temperature of LNG is - 162 C°.

Table 7. GN Flow rate consumed by the boiler

LNG Flow	Turbo-compressor Stopped	Turbo-compressor in service (Speed 6500 Tr/min)
Q GN in Kg/h	15 000 Kg/h	8 800 Kg/h

Analysis of table 07

- The consumption of NG is proportional to the stopping of the turbo-compressor unit [9-10];
- The GN gain (**Compressor** in service) is (15 000 – 8 800 = **6 200 Kg/h**);
- The torch flame will be very high during the Turbo-compressor unit shutdown;
- To feed the boiler, an additional **6 200 kg/h** of NG is required to compensate for the quantity of flared fuel gas (if the turbo-compressor is off);
- The 6 200 kg/h of GN burned in the boiler gives a greater quantity of CO_2, therefore more pollution; (fuel gas is a treated natural gas (GNT));
- **Loss** [11-12]: Quantity = 6 200 Kg/h = 4 152.71 M^3/h (the mass density of NG is 1.493 kg/m^3),
  - Quantity = 32 889 484.26 M^3/Year (based on 330 days)
  - Quantity = 1 305 138.26 MMBTU
  - The loss of the GN economy assuming that the price of MMBTU 4 dollars: is 5 220 553.06 dollars equivalent to 417 644 244.57 DA.

Note

The heat of the steam drawn in by the turbine has not been taken into account because this turbine is under counter pressure (outlet pressure is 4.2 bars and T°: 260oC, this quantity joins the VM circuit (medium pressure steam)) [13-14].

Table 8. Comparison table between gas consumption and maintenance costs [15]

The Cost of Maintenance in DA	The Cost of Gas in DA

5 868 714,60 DA	417 644 244,57 DA

Analysis of table 08

- The maintenance cost is 2% of the annual natural gas consumption.

CONCLUSIONS

In order to realize my inspiration as follows:
Our work was based on a comparative study between the cost of maintenance (spare parts, intervention time for each type, human and material resources, etc.), the consumption of NG in the event of turbocharger immobilization, and the loss of earnings. We determined the major importance of this equipment; its low maintenance cost compared to the very high cost of NG over-consumed by the boiler; its importance on the liquefaction process (lowering the LNG temperature); its impact on the environment by reducing greenhouse gas (CO_2) emissions, and in this sense, recommending the following:

- Ensure the availability of equipment (Put all means);
- It is necessary to disassemble the machine and clean it thoroughly, then inspect it approximately once a year depending on the nature of use;
- All parts should be examined for wear. In this way, any cause of excessive wear will be detected and it will be possible to correct it before damage occurs;
- All oil chambers must be thoroughly cleaned to ensure complete removal of all foreign substances and oil residues;
- Conserve the environment by reducing greenhouse gas (CO_2) emissions;
- In case of shortage of spare parts, on the national and international market, it is necessary to launch a specification relating to the supply of the specific spare part or the installation of new equipment due to the unavailability of spare parts.

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