Sudan University of Science and Technology

College of Graduate Studies

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of M.Sc. in Mechanical Engineering (Power)

Garri Gas Turbines Fuel System Modification

تعديل نظام الوقود في توربينات قري الغازية

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الآيـــــــة

قال الله تعالي:

بسم الله الرحمن الرحيم

لَا يُكَلِّفُ ٱللَّهُ نَفْسًا إِلَّا وُسْعَهَا ۚ لَهَا مَا كَسَبَتْ وَعَلَيْهَا
مَا ٱكْتَسَبَتْ ۗ رَبَّنَا لَا تُؤَاخِذْنَآ إِن نَّسِينَآ أَوْ أَخْطَأْنَا ۚ رَبَّنَا
وَلَا تَحْمِلْ عَلَيْنَآ إِصْرًا كَمَا حَمَلْتَهُۥ عَلَى ٱلَّذِينَ مِن قَبْلِنَا ۚ
رَبَّنَا وَلَا تُحَمِّلْنَا مَا لَا طَاقَةَ لَنَا بِهِۦ ۖ وَٱعْفُ عَنَّا وَٱغْفِرْ لَنَا وَٱرْحَمْنَآ ۚ
أَنتَ مَوْلَىٰنَا فَٱنصُرْنَا عَلَى ٱلْقَوْمِ ٱلْكَٰفِرِينَ ﴿٢٨٦﴾

سورة البقرة - الآية 286

DEDICATION

TO MY MOTHER

TO MY FATHER

TO MY BELOVED, WHO

CONSTANT PRAYER,

SACRIFICE, AND INSPIRATION

LED TO THIS WONDERFUL

ACCOMPLISHMENT

ACKNOWLEDGMENT

All praises and thanks are due to **ALLAH (Subhanaho WA taala)** for bestowing me with health, knowledge, and patience to complete this work.

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Abstract

Garri 1 combined cycle power plant is one of the important power plants in the national grid consisting of 4 (four) gas turbine units, 4 (four) HRSG and 2 (two) steam turbine. The main problem of Garri 1 combined cycle power plant is expensive light diesel fuel oil (LDO),

The price of the used fuel oil in Garri 1 is about 1,739.5 SDG/ton, if we considered that each gas turbine unit consumes about 9 ton/hour at base load, we can estimate the cost of fuel for all units is 62,622.00 SDG/hour.

However these gas turbine units have the option of dual fuel (LDO) light diesel oil and (LPG) liquefied petroleum gas, but due to the lack of production of LPG they are run by LDO mainly, which increases the operational cost of the plant, and accordingly affects the cost of produced kW.h from the plant.

Looking for the solution to this problem is being an important aim of the top management of STPG. Therefore this study concentrated on the available opportunity to transform the fuel type of the plant by using perspective and more low-cost fuel such as:

- Natural Gas (NG).
- Sponge Coke (Gasification).
- Liquefied Petroleum Gas (LPG).
- Heavy Coked Gas Oil (HCGO The last option of fuel (HCGO) is more recommended due to the following reasons:

✧ No availability of the (NG) nearby the plant location, however, this option could be possible if the NG exploration has been succeeding in any part of the country or importing facilities has been constructed.

✧ The production of the sponge coke now from Khartoum Refinery Company (KRC) is enough just to run Garri plant 4 (2x55 MW).

✧ (HCGO) is now used in Dr. Mahmoud Shareef Power Station {Phase I (2 x 30 MW) and Phase II (2 x 60 MW)}, but the efficiency of the units vary between 27 to 30 %, while in Garri 1 combined cycle the efficiency is higher than (47 %).

✧ Transportation of (HCGO) from KRC to the power station is expensive if compared with transported from KRC to Garri power station, which lays beside KRC and fuel oil delivered by a pipeline.

الملخص

تعتبر محطة توليد كهرباء قري (1و2) من أهم محطات التوليد التي تغذي الشبكة القومية و تتكوَّن المحطة من 4 وحدات توربينات غازية و 4 مولّدات بخار بالإسترجاع و 2 وحدة توربينة بخارية .

تواجه محطة كهرباء قري (1و2) مشكلة كبيرة تتمثل في التكلفة العالية لوقود الجازولين الخفيف LDO و الذي يصل سعره لحوالي 1739.5 جنيه سوداني للطن المتري ، و بإعتبار أن إستهلاك الوحدة الغازية الواحدة تستهلك حوالي 9 طن في الساعة في الحمولة القصوي (حوالي 30 ميقاواط)، فإن تكلفة تشغيل الوحدات الغازية الأربعة تصل إلي 62,622 جنيه سوداني في الساعة الواحدة .

و بالرغم من أن هذه الوحدات لها إمكانية إستخدام نوعين من الوقود (الجازولين الخفيف LDO) و (غاز البترول المسال LPG)، إلَّا أن نقص الكمية المنتجة من شركة مصفاة الخرطوم جعلت إستخدام الجازولين الخفيف هو الخيار الوحيد للتشغيل ،وهذا يزيد من تكلفة تشغيل المحطة ، وبالتالي تكلفة الـ kW.hr المنتجة من المحطة .

أصبح البحث عن حل لهذه المشكلة هو الهاجس الأكبر لدى الإدارة العليا للشركة السودانية للتوليد الحراري، وعليه فإنَّ هذه الدراسة ترتكز على توفير خيارات أخرى للوقود بحيث تكون أقل تكلفة مثل :

(1) الغاز الطبيعي NG .
(2) الفحم البترولي (بعد تحويله إلي الحالة الغازية) .
(3) غاز البترول المسال LPG .
(4) الجازولين الثقيل HCGO .

و هذا النوع الأخير HCGO هو الأنسب وذلك للأسباب الآتية :

(1) عدم توفر الغاز الطبيعي بالقرب من المحطة، ولكن هذا المقترح يمكن أن يرى النور في حالة إستكشاف الغاز في أي من الحقول الموجودة في السودان، أو إمكانية إستيراده من الخارج .
(2) كمية الفحم البترولي المنتج من شركة مصفاة الخرطوم KRC يكفي فقط لتشغيل محطة كهرباء قري (4) (55x2 ميقاواط).
(3) وقود الجازولين الثقيل HCGO يستخدم الآن في محطة د. محمود شريف الحرارية، في المرحلتين الأولى (30x2 ميقاواط) ، و الثانية (60x2) ميقاواط) ولكن بكفاءة (27% ~ 30%) وتعتبر أقل نسبياً إذا ما قورنت مع الدورة المزدوجة (محطة قري 1) حيث ترتفع إلي (47%) .
(4) تكلفة ترحيل الوقود من موقع شركة مصفاة الخرطوم لموقع محطة د. محمود شريف عالية نسبياً إذا ما قورنت مع الترحيل لموقع محطة كهرباء قري و التي تقع بالقرب من مصفاة الخرطوم ويتم توصيل الوقود إليها بواسطة خط أنابيب .

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Abbreviations

LDO	light diesel fuel oil
NG	Natural Gas
HRSG	Heat Recovery Steam Generator
LPG	Liquefied Petroleum Gas
HCGO	Heavy Coked Gas Oil
SCR	Selective Catalytic Reduction
LHV	Lower heating value
DLN	Dry Low NO_X
BFGs	Blast Furnace Gases
ASL	Arabian Super Light
ICEs	internal combustion engines
HFO	Heavy fuel oil
STPG	Sudanese Thermal power Generation
KRC	Khartoum Refinery Company
HPE	Harbin Power Engineering Co. Ltd
GE	General Electric

Chapter 1

Introduction

1.1 Introduction

Garri 1 combined cycle power plant is one of the important power plants in the national grid consisting of (four) gas turbine units, (four) HRSG and (two) steam turbine. The main problem of Garri 1 combined cycle power plant is expensive light diesel fuel oil (LDO).

The price of the used fuel oil in Garri 1 is about 1,739.5 SDG/ton, if we considered that each gas turbine unit consumes about 9 ton/hour at base load, we can estimate the cost of fuel for all units is 62,622.00 SDG/hour.

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- Heavy Coked Gas Oil (HCGO).

1.2 Problem statement

The problem of this business case appears in the high operational cost due to the increase in (LDO) fuel prices. The problem takes its importance from the competition between the power generation types, in which the low cost (kW.hr) is highly recommended. And also study effectively in turbine side first, second and third stage bucket.

1.3 Objectives

1.3.1 Main objective

The base case of study is to operate the Garri combined cycle power station with LDO

Use (HCGO) in Garri Power Station, visibility and effective in bucket gas turbine

1.3.2 General objectives:

Reduce use of light diesel oil for other machine and cars.

1.4 Methodology

This option is mainly based on using the (HCGO) as fuel in combination with (LDO) (which will be used only in start-up and shut-down) of gas turbine units in Garri combined cycle power plant.

This option requires some modifications and additional systems to be installed such as heating system, fuel treatment system, filtration skid, etc.

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Chapter 2

Literature Review

2.1 Introduction

Generally, the gas turbine is the most versatile item of turbomachinery today. It can be used in several different modes in critical industries such as power generation, oil, and gas, process plants, aviation, as well as domestic and smaller related industries. A gas turbine essentially brings together air that it compresses in its compressor module, and fuel, that is then ignited. Resulting gases are expanded through a turbine. That turbine's shaft continues to rotate and drive the compressor which is on the same shaft, and operation continues. A separate starter unit is used to provide the first rotor motion until the turbine's rotation is up to design speed and can keep the entire unit running.

The main challenge in designing a combined-cycle plant with a given gas turbine is how to transfer gas turbine exhaust heat to the water/steam cycle to achieve optimum steam turbine output. The focus is on the heat recovery steam generator (HRSG) in which the heat transfer between the gas cycle and the water/steam cycle takes place.

Figure 2.1 shows the energy exchange that would take place in an idealized heat exchanger in which the product, mass flow times specific heat capacity, or the energy transferred per unit temperature must be the same in both media at any given point to prevent energy and exergy losses. **In** order for energy transfer to take place, there must be a temperature difference between the two media. As this temperature difference tends towards zero the heat transfer surface of the heat exchanger tends towards infinity and the exergy losses towards zero. The heat transfer in an HRSG entails losses associated with three main factors:

- The physical properties of the water, steam and exhaust gases do not match causing energetic and energetic losses
- The heat transfer surface cannot be infinitely large The temperature of the feed water must be high enough to prevent corrosive acids forming in the exhaust gas where it comes into contact with the cold tubes. This limits the energy utilization by limiting the temperature to which the exhaust gas can be cooled The extent to which these losses can be minimized (and the heat utilization maximized) depends on the concept and on the main parameters of the cycle. **In** a more complex cycle, the heat will generally be used more efficiently, improving the performance but also increasing the cost. **In** practice, a compromise between performance and cost must always be made.

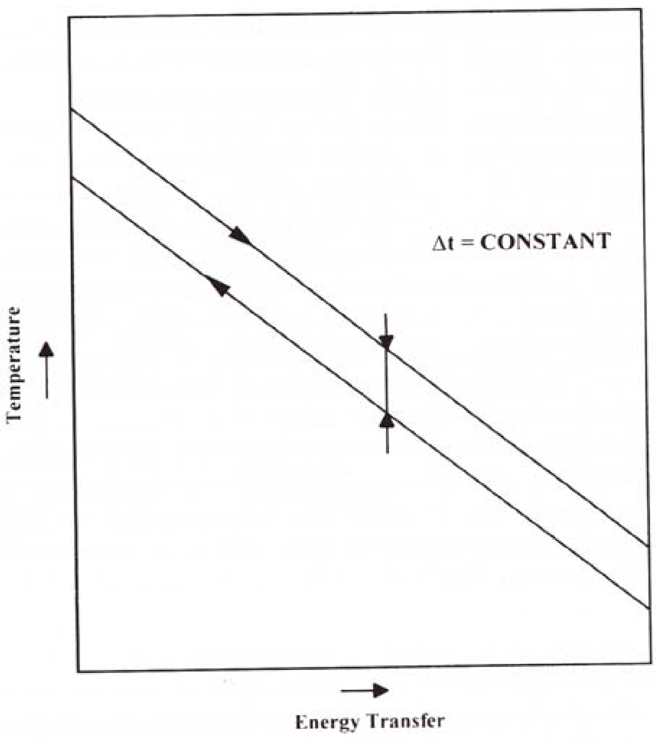


Figure 2.1 Energy/Temperature Diagram for an Idealized Heat Exchanger

2.2 BASIC COMBINED-CYCLE CONCEPTS

In this section, the most common combined-cycle concepts are presented and explained, starting with the most simple and leading to more complex cycles. A heat balance for each of the main cycle concepts is given, based on ISO conditions (ambient temperature 15°C, (59°F); ambient pressure 1.013 bar, (14.7 psi); relative humidity 60%; condenser vacuum 0.9 bar ; sequential combustion gas turbine, rated at 41.259 MW and a steam turbine with water cooled condenser. The gas turbine is equipped with cooling air coolers that generate additional steam for the water/steam cycle and boost the steam turbine output. Due to the fact that these features are the same for all of the heat balances, a clear comparison can be made between them showing how the cycle concept influences the heat utilization.

2.3 Fuel Gas Classification

General

G.E. heavy-duty gas turbines have the ability to burn a wide range of gaseous fuels as shown in Table 1. These gases present a broad spectrum of properties due to both active and inert components. This specification is designed to define guidelines that must be followed in order to burn these fuels in an efficient, trouble-free manner while protecting the gas turbine and supporting hardware

Table 2 specifies the allowable limits for both

the fuel properties and contaminants. Table 3 identifies the acceptable test methods to be used in determining gas fuel properties table(2.1):-

TABLE FUEL GAS CLASSIFICATION		1
F U E L	LHV Btu/SCF .	MAJOR COMPONENTS
Natural gas	800-1200	Methane
Liquefied Petroleum Gas (LPG)	2300-3200	Propane, Butane
ation Gases *-Air Blown*	100-150	Carbon monoxide, Hydrogen, Nitrogen, Water Vapor
-Oxygen Blown	200-400	Carbon monoxide, Hydrogen,:, Oregon, Water Vapor
Process Gass	300-1000	Methane, Hydrogen, Carbon monoxide, Carbone dioxide

T A B L E 2

GAS FUEL SPECIFICATION

FUEL PROPERTIES	MAX		I MIN		NOTES
Lower Heating Value, Btu/lb Modified Wobbe Index Range Superheat, °F Flammability Gas Constituent Limits, % by volume: Methane Ethane Propane Butane + Paraffine (C4+) Hydrogen	None +5% — See Note 7 .' 100 1 5 1 5		100 — 300 — 5% 50 >2.2:1 - • 85 0 0 0 • 0 0		See note 3 See Notes 4,5 See Note 6 Rich to lean fuel to air ratio, volume basis See Note 8 % of reactant species % of reactant species % of reactant species % of reactant species
CONTAMINANTS (See Notes	FUEL LIMITS ppmw (See Note 14)				NOTES
Particulate Total	MS3000	B/E	F	H	See Note 15
Above 10 Microns	35 0.4	32 0.3	23 0.2	23 0.2	• -
Trace Metals Sodium plus	0.8				See Note 16
Liquids	0				No Liquids allowed, see superheat requirements and Note 17

- **Notes:**

1. All fuel properties must meet the requirements from ignition to baseload unless otherwise stated.

2. Values and limits apply at the inlet of the gas fuel control module.

3. Heating value ranges shown are provided as guidelines. Specific fuel analysis must be furnished to GE for proper analysis.

4. See section2.4-B. for the definition of Modified Wobble Range.

5. Variations of Modified Wobble Index greater than + 5% or -5%.may be acceptable for some applications, (i.e. On units that incorporate gas fuel heating). GE must analyze and approve all conditions where the 5% variation is to be exceeded.

6. Minimum fuel gas temperature shall be set at 50°F above the higher of the Hydrocarbon (including Glycerin) or Water Dew points

7. There is no defined maximum flammability ratio limit. Fuel with flammability ratio significantly larger than those of natural gas may require a start-up fuel.

8. The range of constituents is for typical natural gas. Fuels meeting these limits are approved for operation with the entire GE heavy-duty gits turbine product line, including those utilizing Dry Low NO_x combustion systems. Candidate fuels which do not meet these limits should be referred to GE for further review. All fuels will be reviewed by GE on a case by case basis

9.The quantity of sulfur in gas fuels not limited by this specification. Experience has shown that oxidantion/corrosion rates are not significantly affected by fuel sulfur levels up to 1% sulfur. Hot corrosion of hot gas path parts is controlled by the specified trace metal limits. Sulfur levels shall be considered when addressing HRSG Corrosion, Selective Catalytic Reduction (SCR) Deposition, Exhaust Emissions, System Material Requirements, Elemental Sulfur Deposition and Iron Sulfide

10. When fuel heating for thermal efficiency improvements is utilized (e.g. Tfuel > 300°F) there is a possibility of gum formation if excess aromatics are present. Contact GE for further information.

11. Minimum and maximum gas fuel supply pressure requirements are furnished by GE as part of the unit proposal.

12. The contamination limits identified represents the total allowable limit at the inlet to the turbine section. These limits will be reduced if comparable contaminants are in compressor CJ 1: t.air and combustion steam/water injection.

13. The contamination limits and the identified method of calculating contamination_limit apply to "typical" natural gases. Consult GE for contamination limits 'for gasification

14. Given contaminant limits are for pure methane gas. Actual maximum limits are determined by multi -' tip lying given limits by (Actual Fuel LHV/Methane LHV)

15. The fuel gas delivery system shall be designed to prevent the generation or the admittance of solid particulate to the gas turbine gas fuel system. This shall include but not be limited to particulate filtration and noncorrosive (i.e. stainless steel) piping from the particulate filtration to the inlet of the gas

turbine equipment. Fuel gas piping systems shall be properly cleaned/flushed and maintanned prior to gas turbine operation

16. Sodium and potassium, from salt water, are the only corrosive trace metal contaminants normally found in natural gases. Other trace metal contaminants may *be* found in Gasification and Process Gases. These will be reviewed by GE on a case by case basis.

17. The fuel gas supply shall be 100% free of liquids. Admission of liquids can result in combustion and/or hot gas path component damage.

TABLE (2.2):-

TEST METHODS FOR GASEOUS FUELS	
PROPERTY	ASTM METHOD
Gas Composition to C6+ (gas chromatography)	D 1945
Heating Value	D 3588
Specific Gravity	D 3588
Compressibility Factor	D 3588
Dew Point (Note 1)	D 1142
Sulfur (Note 2)	D 3246

2.3.1 Natural and Liquefied Petroleum Gas (LPG):

Natural gases are predominantly methane with much smaller quantities of slightly Hydrocarbons such as ethane, propane, and butane. Liquefied petroleum is a propane and/or butane traces of heavier hydrocarbon.

2.3.1.1Natural gas

Natural gases normally fall within the calorific heating value range of 800 to-1200 Btu per standard cubic foot. Actual calorific heating values are dependent on the percentages of hydrocarbons and inert gases contained in the gas. Natural gases are found in and extracted from underground reservoirs. These "raw gases" may contain varying degrees of nitrogen, carbon dioxide, hydrogen sulfide, and contain contaminants such as salt water, sand, and dirt. Processing by the gas supplier normally reduces and/or removes these constituents and contaminants prior to distribution. A gas analysis must be performed to ensure that the fuel supply to the gas turbine meets the requirements of this specification.

2.3.1.2Liquefied Petroleum Gases:

The heating values of Liquefied Petroleum Gases (LPG) normally fall between 2300 and 3200 Btu/ SCF (LHV). Based on their high commercial value, these fuels are normally utilized as a back—up fuel to the primary gas fuel for gas turbines. Since LPG are normally stored in a liquid state, it is critical that the vaporization process and gas supply system maintains the fuel at a temperature above the minimum required to superheat value. Fuel heating and heat tracing are required to ensure this.

2.3.2 Gasification Fuels:

Other gases that may be utilized as gas turbine fuel are those formed by the gasification of coal, petroleum coke or heavy liquids. In general, the heating values of gasification fuel are substantially lower than other fuel gases. These lower heating value fuels result in the effective areas of the fuel nozzles being larger than those utilized for fuels of higher heating values.

Gasification fuels are produced by either an Oxygen Blown or Air Blown gasification process.

2.3.2.1Oxygen Blown Gasification:

The heating values of gases produced by oxygen-blown gasification fall in the range of 200 to 400 BtuISCF. The Hydrogen (I-1_2) content of these fuels are normally above 30% by volume and have H2ICO mole ratio between 0.5 to 0.8. Oxygen-blown *gasification* fuels are often mixed with steam for thermal NOx control, cycle efficiency improvement and/or power augmentation. When utilized, the steam is injected into the combustor by an independent passage. Due to the high hydrogen content of these fuels, oxygen-blown gasification fuels are normally not suitable for Dry Low NOx (DLN) applications. (See Table 2) The high flame speeds resulting from high hydrogen fuels can result in flashback or primary zone re-ignition on DLN premixed combustion systems. Utilization of these fuels shall be reviewed by GE

2.3.2.2Air Blown Gasification:

Gases produced by air blown gasification normally have heating values between 100 and 150 BTU/ SCFH. The Hydrogen (11,) content of these fuels can range from 8% to 20% by volume and have a 1-14C0 mole ratio of 0.3 to 3:1. The use and treatment of these fuels are similar to those identified for oxygen-blown gasification.

For Gasification fuels, a significant part of the total turbine t low comes from the fuel. In addition, for oxygen blown fuels there is a diluents addition for NOx control. Careful integration of the gas turbine with the gasification plant is required to assure an operable system. Due to the low volumetric heating value of both oxygen an air blown gases, special fuel system and fuel nozzles are required.

2.3.3 Process Gases:

Many chemical processes generate surplus gases that may be utilized as fuel for gas turbines. (i.e. tailor refinery gases). These gases often consisting of methane, hydrogen, carbon monoxide, and carbon dioxide that are normal byproducts of petrochemical processes. Due to the hydrogen and carbon monoxide content, these fuels have large rich to lean flammability limits. These types of fuels often require inerting and purging of the gas turbine gas fuel system upon unit shutdown or a transfer to a more conventional fuel. When process gas fuels have extreme flammability limits such that the fuel will auto-ignite at turbine exhaust conditions, a more "conventional" startup fuel is required.

Additional process gases utilized as gas turbine fuels are those which are by-products of steel production.

These are:-

1. Blast Furnace Gases (BFGs)

Blast Furnace Gases (BFGs), alone, have heating values below minima, allowable:-limits: Gases must be blended with other fuel to raise the heating value to above the required limit. Coke Oven and/or Natural Gases or hydrocarbons such as propane or butane ‘can be utilized to accomplish this

2. Coke Oven Gases

Coke oven gases are high in II, and CH4 and may be used as fuel for non-Dry Low NOx (DLN) combustion systems. These fuels often contain trace amounts of heavy hydrocarbons, which when burned could lead to carbon buildup on the fuel nozzles. The heavy hydrocarbons must be "scrubbed" or removed from the fuel prior to delivery to the gas turbine.

3. CORER Gases

CORER gases are similar to oxygen blown gasified fuels and may be treated as such. They are usually lower in H2 content and have lower heating values than oxygen blown gasified fuels.

2.4 FUEL PROPERTIES

A. Heating Values

A fuel's heat of combustion, or heating value, is the amount of energy, expressed in Btu•(British Thermal Unit), generated by the complete combustion, or oxidation, of a unit weight of fuel'. The amount of heat generated by complete combustion is a constant for a given combination of combustible elements and compounds.

For most gaseous fuels, the heating value is determined by using constant pressure, continuous type calorimeter. This is the industry standard. In these units, combust:1_4,e substances are burned with oxygen under essentially constant pressure conditions. In all fuels that contain hydrogen, water vapor is a product of combustion, which impacts the heating value. In a bomb calorimeter, the products of combustion are cooled to the initial temperature and all of the water vapor formed during combustion is condensed. The result is the HHV, or higher heating value, which includes the heat of vaporization of water. The LHV, or lower heating value, assumes all products of combustion including water remain in the gaseous state, and the water heat of vaporization is not available.

B. Modified Wobble Index Range

While gas turbines can operate with gases having a very wide range of heating values, the amount of variation that a single specific fuel system can accommodate is much less. Variation in heating value as it affects gas turbine operation is expressed in a term identified as modified Wobbe Index (Natural Gas, E. N. Tiratsoo, Scientific Press Ltd., Beaconsfield, England, 1972). This term is a measurement of volumetric energy and is calculated using the Lower Heating Value (LHV) of the fuel, specific gravity of the fuel with respect to air at ISO conditions, and the fuel temperature. The mathematical definition is as follows:

$$\text{Modified Wobbe Index} = \frac{LHV}{\sqrt{SGgas \ x \ T}}$$

This is equivalent to:

$$\text{Modified Wobbe Index} = \frac{LHV}{\sqrt{\frac{MWgas}{28.96} \ x \ T}}$$

Where:

LHV	=	Lower Heating Value of the Gas Fuel (Btu/scf)
SGgas	=	Specific Gravity of the Gas Fuel relative to Air
MWgas	=	Molecular Weight of the Gas Fuel
T	=	Absolute Temperature of the Gas Fuel (Rankine)
28.96	=	Molecular Weight of Dry Air

The allowable modified Wobble Index range is established to ensure that required fuel nozzle pressure ratios are maintained during all combustion/turbine modes of operation. When multiple gas fuels are supplied and/or if variable fuel temperatures result in a Modified Wobble Index that exceeds the 5% limitation, independent fuel gas trains, which could include control valves, manifolds, and fuel nozzles, may be required for standard combustion systems. For DLN systems, an alternate control method may be required to assure that the required fuel nozzle pressure ratios are met. An accurate analysis of all gas fuels, along with fuel gas temperature profiles shall be submitted -*J* GE for proper evaluation.

C. Superheat Requirement

The superheat requirement is established to ensure that the fuel gas supplied TFA the gas turbine is 100% free of liquids. Dependent on its constituents, gas entrained liquids could cause degradation of gas fuel nozzles, and for DLN applications, premixed flame flashbacks or re-ignition. 50°F of superheat is specified to provide enough margin to compensate for temperature reduction due to the pressure drop across the gas fuel control valves.

D. Flammability Ratio

Fuel gases containing hydrogen and/or carbon monoxide will have a ratio of rich-to-lean flammability limits that is significantly larger than that of natural gas. Typically, gases with greater than 5% hydrogen by volume fall into this range and require a separate startup fuel. GE will evaluate the gas analysis to determine the requirement for a start-up fuel.

Fuel gases with large percentages of an inert gas such as nitrogen or carbon dioxide will have a ratio of rich—to—lean flammability limits less than that of pure natural gas. Flammability ratios of less than 2.2to 1 as based on volume at ISO conditions (14.696 psi and 59°F), may experience problems maintaining stable combustion over the full operating range of the turbine

E. Gas Constituent Limits

Gas constituent limits are set forth to assure stable combustion through all gas turbine loads and modes of operation. Limitations are more stringent for Dry Low NOx combustion systems where "premixed" combustion is utilized. Detailed gas analysis shall be furnished to GE for proper evaluation.

F. Gas Fuel Supply Pressure

Gas fuel supply pressure requirements are dependent on the gas turbine model and combustion design, the fuel gas analysis and unit specific site conditions. Minimum and maximum supply pressure requirements will be furnished by GE as part of the unit proposal.

IV. CONTAMINANTS

Dependent on the type of fuel gas, the geographical location and the forwarding means there is the potential for the "raw" gas supply to contain one or more of the following contaminants: Water, salt water, Iron sulfide, Scrubber oil or liquid, Compressor Lube oil, etc..

2.5 Assumption of calculation:-

All data collected from the garri1,2 power station, department off efficiency and planning, monthly reports.

-fuel comparison is between (LDO, HCGO).

-Averages are taken for one block by dividing by 4.

- Estimated base load for each block 90 MW(each block consists of 2GT unit and 1 ST unit)

-the load calculation is base on 24 hours a day 320 for 1 year (subtract 45 days for maintenance work)

- 1 Block =30 MW * 3 unit * 24 hours * 320 days = 691200 MW output

KW.hr price (SDG/KW.hr)= total cost/ Actual sent energy

-Auxiliary consumption = 0.02538*691200= 17543 MW

Total cost (operation cost , maintenance cost, fuel cost , depreciation cost , insurance ,

density LDO=1.215

Fuel price are (2179.481 SDG/ton for LDO , 331.32 SDG/ton for

Maintenance cost is increased by10%,20%,30%,40%,40% and 50% to meet modifications

Auxiliary power consumption average calculated=2.538% of total generated load.

Total sent energy =total output – auxiliary consumption

- Operational cost using (fuel type) = consumption of fuel* fuel Price

-Kw.h price according to fuel=cost of fuel*consumption fuel / total sent energy

- Efficiency η= total output(MW) / input(MW)

- Heat rate = $1/\eta$

Since:

Input= $\dot{m}_f$ *caloric value of fuel

2.6 literature review:-

In the case of study Robert M. Jones & Norman Z. Shilling worked at general electric (2011). They Focus on improvements in gas turbine technology that contributed to the commercialization and leadership of Integrated Gasification Combined Cycle systems for the clean conversion of refinery residues and solid wastes to economical “poly-generation “of power and other high valued by-products used by the refiner. GE gas turbines have accumulated more than 499,000 fired hours on synthesis fuel gas (of which 132,000 hours were fired on syngas derived from refinery feedstocks). This broad experience—enabled in large part by developments in gas turbine technology— serves as a superb entitlement for environmentally superior value generation from poor quality, low-cost opportunity fuels.[3]

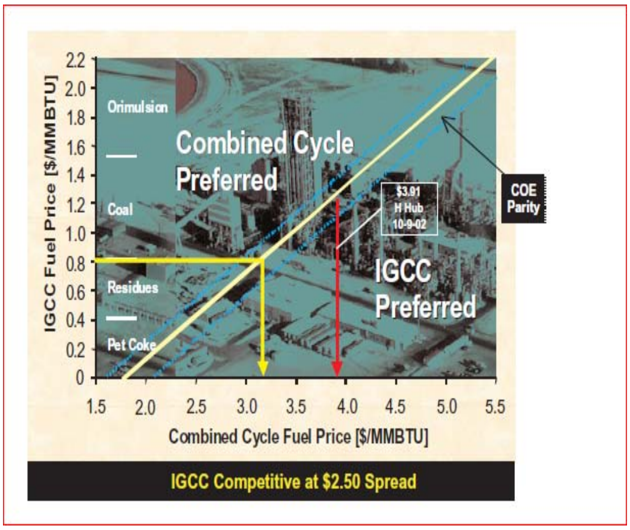


Figure 2.2 Break-even fuel price comparison

At GE’s Global Research Laboratory, advanced combustion concepts for single-digit NOx are in the conceptual planning stage with promise for additional application to syngas and long term emissions reduction. natural gas prices of $2.5 per MMBtu higher than IGCC fuel prices, IGCC provides a cost of electricity equivalent to NGCC. Current natural

gas pricing (e.g., Henry Hub-$3.91/MMBtu- HHV, 10/9/02) would suggest that COE from

refinery-based IGCC plants fueled by low-cost opportunity fuels (e.g., residuals or pet coke)

should be significantly lower than NGCC plants with spot-market fuel pricing. Contemporary IGCC plant designs are commercially viable with refinery operations owing to their broad capability to use the opportunity and low-value waste fuels.

Also in the report of Mr. Jeffrey Goldmeer, Ph.D. at (2014), made studied for heavy liquid fuels, such as crude oil or heavy fuel oil can be used for power generation, but these ash-bearing fuels are traditionally only used on E-class turbines, in part because of the high levels of metal contaminants. However, some crude oils have the potential to be used in F-class turbines. One particular crude oil, Arabian Super Light (ASL), has the potential to be used as a fuel on a heavy-duty gas turbine as ASL has unique properties relative to other crude oils, including low levels of vanadium. This paper presents a case study in GE's fuel evaluation process using the ASL as an example of the steps required to validate a new fuel for use in a gas turbine. Using this process GE determined that ASL is a viable fuel for use in F-class gas turbines, and concluded with a successful field demonstration on a GE 7F gas turbine in Saudi Arabia. This was a significant milestone as it was the first time that crude oil was operated in an F-class gas turbine.[4]

Modern gas turbines are able to operate on a large range of gas and liquid fuels, and the number of fuels these systems is able to operate how best to use their domestic natural resources. In the case of ASL, the evaluation process provided a positive result. Following the successful completion of the ASL demonstration testing in December 2013, the customer fully commissioned the plant on ASL, becoming the first F-class power plant to be able to operate on crude oil. This evaluation of ASL was an important step for power generation in Saudi Arabia as this fuel has been selected as the back-up fuel for multiple combined cycle power plants, which include 27 GE 7F gas turbines. Once all of these units are fully commissioned, they will provide more than 4.4 GW of power for Saudi Arabia.

Otherwise in the report of the total generation capacity in Myanmar (2015) is 4,581MW, of which 3,044MW (66.4%) is from hydropower. Only 33% of the population has access to electricity. Myanmar needs substantially more generating capacity since its socio-economic development is hampered by lack of electricity. Myanmar is mapping a National Electricity Master plan to meet increasing demand, setting its sights on boosting capacity from 4,581MW to over 27,000MW in 2030. Myanmar plans to shift the focus from hydropower to other energy sources, including coal, natural gas, solar, and wind power by 2030. High reliance on hydropower causes unstable supply, as the storage in reservoirs shrinks during the hot season. The paper proposes an optimum energy mix for Myanmar in line with common practice in developing countries. Flexible internal combustion engines (ICEs) based power plants offer excellent fuel efficiency and reliability. These gas-based power plants are quick to respond, efficient and, can make optimum use of available gas. The dual-fuel combustion engine power plants can be optimized to initially run on cheap liquid fuel (HFO or crude oil) and later use natural gas when it’s eventually tapped from the proven reserves of 11Tcf. Such generating units have proved their worth in meeting peaking and reserve requirements and in providing necessary back-up for renewable energy that tends to be intermittent. The optimal technology for each project must be chosen based on a feasibility study specific to the project. This paper analyzes the life cycle costs of a dual fuel combined cycle gas turbines and ICEs plants separately. Based on the feasibility study, combustion engines based dual fuel plant has lower total life-cycle cost than gas turbine power plant. Total saving in base load operation is 92 Million USD over 4 years of liquid fuel operation and 217 Million USD over the project lifetime. The dual fuel combustion engine plants provide the best possible effect on HFO& gas mode, as well as the lowest life-cycle costs when compared to gas turbine technologies. Greater efficiency of ICE plants would also allow the same amount of fuel to produce more electricity as gas turbines, thus reducing the impact of restricted gas supplies in Myanmar.[5]

And also case was studied (H.E. von Doering, and M.B. Hilt) in (2014) World events have highlighted the critical role that fuels play in power production. The cost and availability of fuel are preeminent planning considerations. Consequently, the ability of any prime mover to burn a wide range of fuels-or fuels flexibility-continues to be of primary importance.

GE heavy-duty gas turbines have operated successfully Burning alternate gaseous fuels with heating values ranging from 11.2 to 116 MJ/m3 (300 to 3100 Btu/ft3 lower heating value (LHV). A listing of gas turbines with alternate gaseous fuel capability by type of fuel, model series, and year of shipment is presented.On the basis of single combustor tests in the laboratory, the capability for successful operation with fuel heating values as low as 4 MJ/mS (110 Btu/ft3) LHV has been demonstrated. More recently GE initiated a program of extensive analytical calculations to investigate the combustion characteristics of a number of lower-heating-value fuels, typical of those produced by a fuel-conditioning process. The analytical calculations were coupled with atmospheric burner tests using a small scale diffusion flame burner. Based upon the results of this study, full-scale single-burner and sector tests were conducted in the Gas Turbine Development Laboratory to confirm expected MS5000 and LM2500 engine performance. An example of the benefits derived from this extensive program is the finding that both the MS5000 and LM2500 gas turbines will operate satisfactorily

While burning a 15.8 MJ/m3 (425 Btu/ft3) gas that comprised nearly 80 percent CO* by volume. In general, the only change required to the standard combustion system is a modification of the gas fuel nozzle to handle the increased volume of fuel. A variation in the heating value of more than +20 percent could be tolerated while still maintaining adequate combustor performance.

The selection of the type of liquid gas turbine fuel is important because the fuel is generally the largest single annual cost item.[6]

Also (someone forms G.E company at 2009) the steady growth of power demand in the Middle East continues

to drive governments, power authorities and independent power providers to look for solutions to meet country as well as regional energy requirements. To provide for these increasing energy

requirements, these organizations must cope with issues of fuel supplies and cost. Fuel supply is further complicated when considering the global competition for what could be

a local generation fuel and increasing environmental awareness. These factors contribute to the region's interests in the diversification of supply and the potential in what may have been considered
margin fuels for generation. In addition, these factors contribute to a greater interest to consider a diverse fuel spectrum allowing for increased operational flexibility and cost control, with improved plant efficiency and emissions characteristics.

Gas turbine based generation systems offer efficient energy Conversion solutions for meeting the challenge of fuel diversity while maintaining superior environmental performance. Combustion design flexibility allows operators a broad spectrum of gas and liquid fuel choices, including emerging synthetic choices. Gases include
and are not limited to ultra-low heating value process gas, syngas, ultra-high hydrogen or higher heating capability fuels. Liquid fuels, considered by some outside the Middle East as a "back up" fuel to natural gas, are a mainstay for the region. This includes Heavy Fuel Oil, which is a primary fuel for many power generation applications in the Middle East. This paper will address the broad range of fuel options in the context of proven, available technology and introduces product solutions tailored to meet fuel flexibility demands expected by the larger generation community.[7]

Chapter 3

Methodology

3.1 Introduction

Garri 1 combined cycle power plant is one of the important power plants in the national grid consisting of 4 (four) gas turbine units, 4 (four) HRSG and 2 (two) steam turbine. The main problem of Garri 1 combined cycle power plant is expensive light diesel fuel oil (LDO). The price of the used fuel oil in Garri 1 is about 1,730 SDG/ton, if we considered that each gas turbine unit consumes about 9 ton/hour at base load, we can estimate the cost of fuel for each unit is 62,280.00 SDG/hour.

However these gas turbine units have the option of dual fuel (LDO) light diesel oil and (LPG) liquefied petroleum gas, but due to the lack of production of LPG they are run by LDO mainly, which increases the operational cost of the plant, and accordingly affects the cost of produced Kwh from the plant.

Looking for the solution to this problem is being an important aim of the top management of STPG. Therefore this study concentrated on the available opportunity to transform the fuel type of the plant by using perspective and more low-cost fuel such as:

- Natural Gas (NG).
- Sponge Coke (Gasification).
- Liquefied Petroleum Gas (LPG).
- Heavy Coked Gas Oil (HCGO).

The last option of fuel (HCGO) is more recommended due to the following reasons:

- No availability of the (NG) nearby the plant location, however, this option could be possible if the NG exploration has been succeeding in any part of the country or importing facilities have been constructed.
- The production of the sponge coke now from Khartoum Refinery Company (KRC) is enough just to run Garri plant 4 (2x55 MW). (HCGO) is now used in Dr. Mahmoud Shareef Power Station {Phase I (2 x 30 MW) and Phase II (2 x 60 MW)}, but the efficiency of the units vary between 27 to 30 %, while in Garri 1 combined cycle the efficiency is higher than (47 %).
- Transportation of (HCGO) from KRC to the power station is expensive if compared with transported from KRC to Garri power station.

The implementation of this transformation is decided to be done by the main contractor, Harbin Power Engineering Co. Ltd. (HPE) since they have easy access to the manufacturers of the gas turbines, heat recovery steam generators, and steam turbines. They already started to study the new situation of using (HCGO) in Garri combined cycle power station with all considerations of the effects of this fuel on the units and their auxiliaries.

- The table below summarized the financial analysis and findings due to the planned modification

Table (3.1) :-

Characteristic	Using LDO	Using HCGO
Unit consumption per day –ton	-	-
Fuel cost per day	-	-
Availability	-	-
Kwh cost	-	-

3.2 Option – Use (HCGO) in Garri Power Station:

3.2.1 Description:

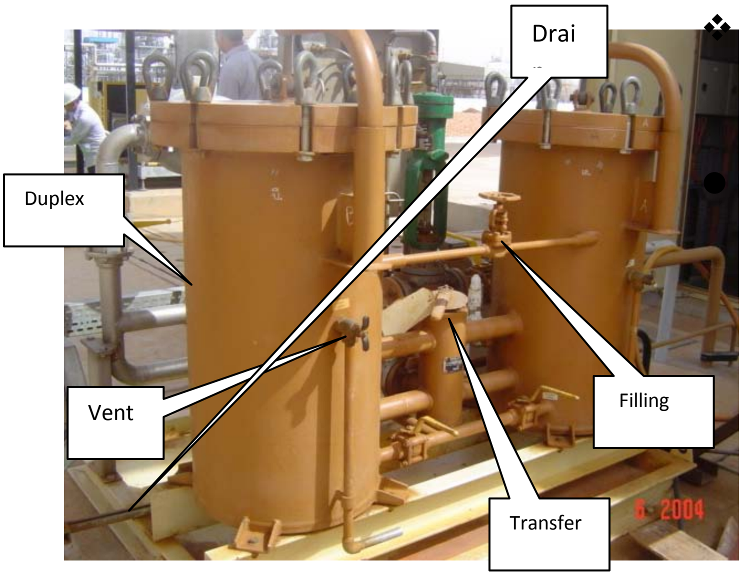
This option is mainly based on using the (HCGO) as fuel in combination with (LDO) (which will be used only in start-up and shut-down) of gas turbine units in Garri combined cycle power plant.

This option requires some modifications and additional systems to be installed such as heating system, fuel treatment system, filtration skid, etc.

3.3Liquid Fuel System

General

When liquid fuel oil is selected for gas turbine operation this system will pump fuel from the fuel oil storage tank by fuel forwarding pump. The discharge of fuel oil forwarding pump go to a low-pressure filtration system (duplex filter) and regulate pressure by regulating valve before go to fuel oil stop valve. When ignition permissive (purge sequence complete and turbine speed at 18%) fuel oil stop valve open the oil to the main fuel oil pump, driven by accessory gear, to boost the pressure of fuel oil before going to high-pressure filter and flow divider consequently. Flow divider divides equal fuel oil flow to each of the ten combustion chambers. Fuel oil flow will be at the proper pressure and flow rate to meet all of the starting, acceleration and loading requirements of gas turbine operation.[8]



- **Function description of the fuel oil system:**

- **Low-pressure filter**

Fuel oil at low pressure, from the fuel forwarding system, is filtered by the low pressure (primary) oil filter, before passing through the solenoid.

Fig 3.1 Duplex filter

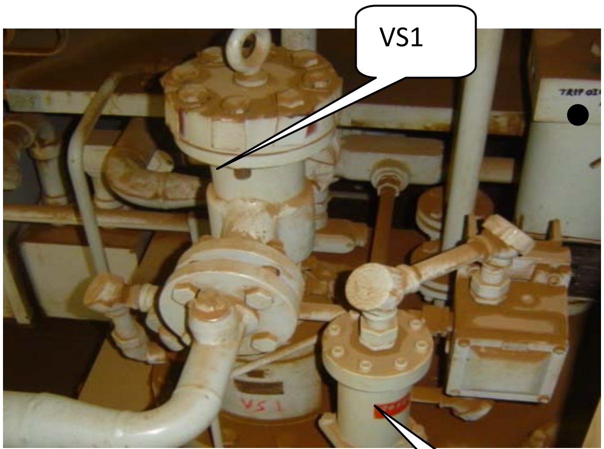
operated fuel stop valve VS 1 and entering the fuel pump. The low pressure is mounted near the accessory base and consist of 5 microns, pleated paper element with oversize contamination capacity. Therefore, clean fuel is normally supplied to the turbine system, however, the low-pressure filter will prevent any contaminants that might be in the

the system from passing through and damaging or interfering with the proper functioning of the fuel stop valve and the fuel pump

.

Before the low-pressure filter, there is a relief valve for each side of the filter which protects the supply circuit against overpressures.

Fig 3.2 relief valve

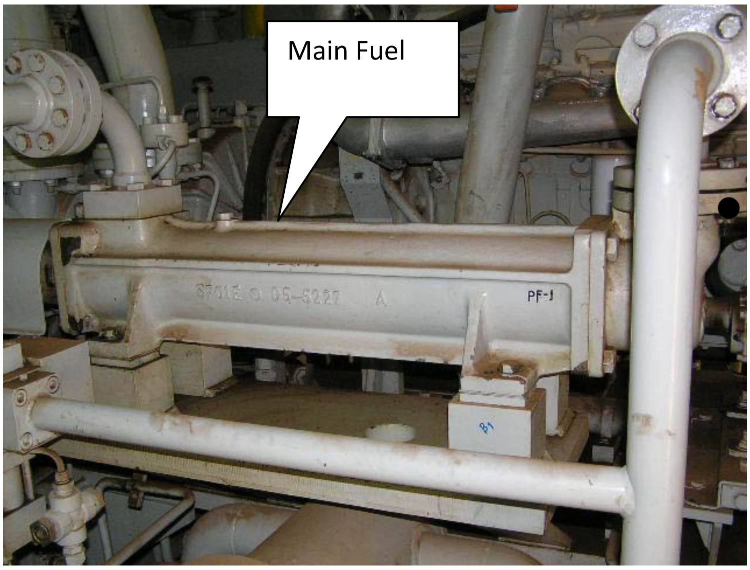


- **Fuel oil stop valve**

Fuel oil stop valve VS1 is an emergency valve, operated from the protection system, which shut off the supply of fuel to the turbine during normal or emergency shutdowns.

Fig 3.3 stop valve

This valve is a special purpose, hydraulically operated, two positions (open and close) valve with a venture disc and valve seat. When the turbine is shut down in the normal sequence, or by an emergency or over speed trip condition, the fuel oil stop valve will fully close within 0.5 second total elapsed time. During normal operation of the turbine, the stop valve is held open hydraulically by trip oil pressure. For normal start up and shut down sequence operation and for electrical trips from the control panel, an elector hydraulic trip servo valve shut off the hydraulic oil flow to the fuel oil stop valve hydraulic cylinder. The spring in the fuel oil stop valve then overcomes the oil pressure and closes the valve.



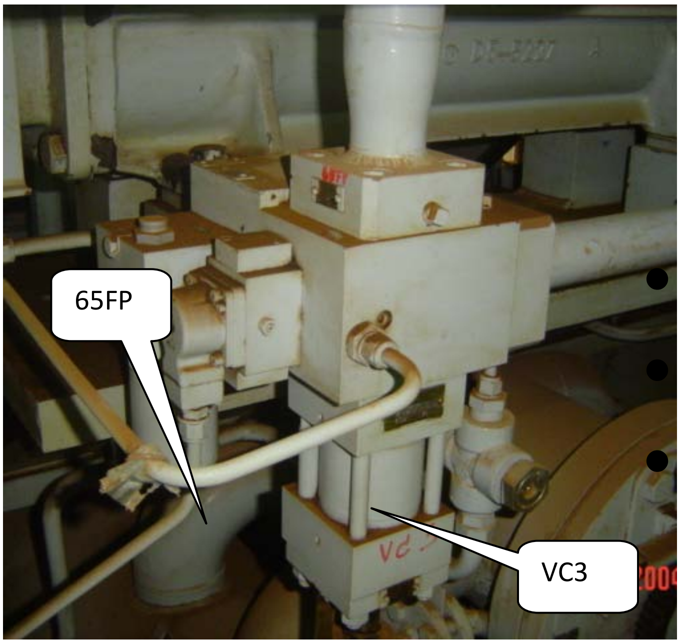
- **Fuel pump**

Liquid fuel pump PF1 is a continuous output screw pump type

driven by the gas

turbine accessory gear and sized to deliver an excess of fuel.

Fig 3.4 main fuel pump



- **Bypass valve**
- **assembly and fuel oil**
- **servo valve**

High-pressure flow from the pump is modulated by the servo controlled bypass valve

Fig 3.5 bypass fuel valve

assembly VC3. Components of this assembly include the bypass valve body electro-hydraulic servo valve 65FP, the electro-hydraulic cylinder, and relief valve VR4. this bypass valve is connected between the inlet and discharge sides of the fuel oil pump and meters the flow of fuel to the turbine by subtracting excess fuel delivered by the pump and bypassing it back to the pump inlet.

The servo valve 65 FP controls the bypass valve stroke according to the different requirement and the sensed fuel flow. If the fuel requirement exceeds the actual oil flow, the bypass valve closes to increase the net oil flow to the turbine. The servo valve uses high-pressure hydraulic oil (cleansed of the contaminant by a metal filter FH3) to actuate the hydraulic cylinder and thus position the bypass valve. The FH3 filter has a delta p indicator to show filter dirty.

- **Pressure relief valve VR4**

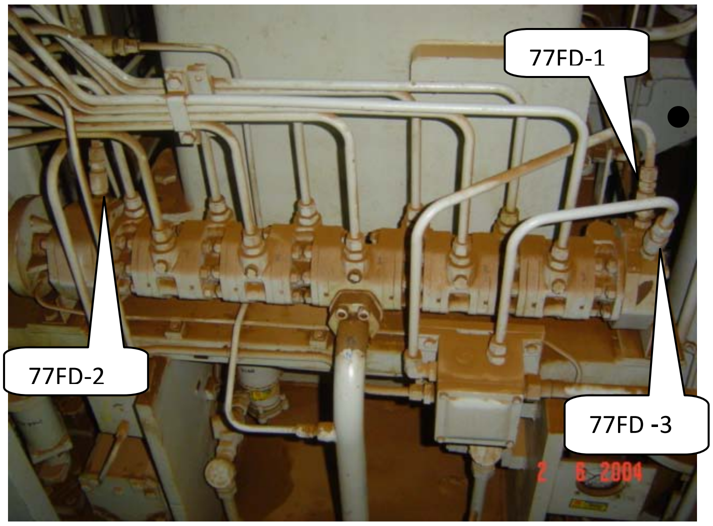
Installed on the fuel oil bypass valve assembly, is also connected by piping between the discharge and inlet side of the fuel pump. Its function is to protect the fuel pump against possible damage from excessive pressure.

- **High-pressure oil filter**

Fuel oil at pump discharge pressure passed through the high pressure (secondary) fuel filter as it flows from the fuel pump to the flow divider. This filter helps to assure that contaminants such as pipe scale are retained and prevented from entering

Fig 3.6 High pressure filter

the flow divider. Five microns pleated paper element provides filtration.



- **Flow Divider**

The purpose of the flow divider FD1 is to apportion fuel oil to each of the fuel nozzles of the turbine. The distribution has ten pump element(inline) with

Fig 3.7 Flow Divider

the inlet port located at the midpoint where the fuel oil enters the unit and is distributed by an internal manifold to the inlet side of each pump element. Fuel is then accurately apportioned through the outlet port of each pump element to a corresponding turbine fuel nozzle. The flow from each pump element is proportional to the speed at which the unit operates.

Each of the pump element consists of two equal size gear rotating in a closely fitted case. The driving gear and shafts are interconnected by splined coupling. A gear indicator, located in each faceplate, is connected to each end drive shaft. The operation is self-sustaining by the flow of fuel oil through the flow divider.

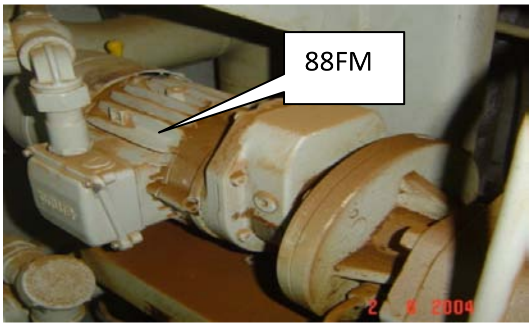
The speed of flow divider pumping elements is directly proportional to the flow delivered to the combustion chamber. Three magnetic picks up assemblies 77FD-1, 77FD-2, and 77FD-3, fitted to the flow divider, produce the flow feedback signal at a frequency proportional to fuel flow delivered to the combustion chambers. This signal is fed to the SPEED TRONIC where it is used in the fuel control system.

The pickup adapters are located on the flow divider. The face plate at each end of the unit has a scaling nut and stud located in the threaded hold provide for the connection of magnetic pickup.

The pickup sensor consists of a permanent magnet, surrounded by the coil in a hermetically sealed, externally threaded metal case. A lock nut is provided on the case for setting the clearance between the pickup and the flow divider gear element. Hermetically sealed pickup leads are of sufficient length to reach to the junction box.

The magnetic flux in the pickups changes with the distance of the pickup tip to the gear element surface. This creates an alternating voltage output of the magnetic pickups as the gear element passed beneath the pickup tip.

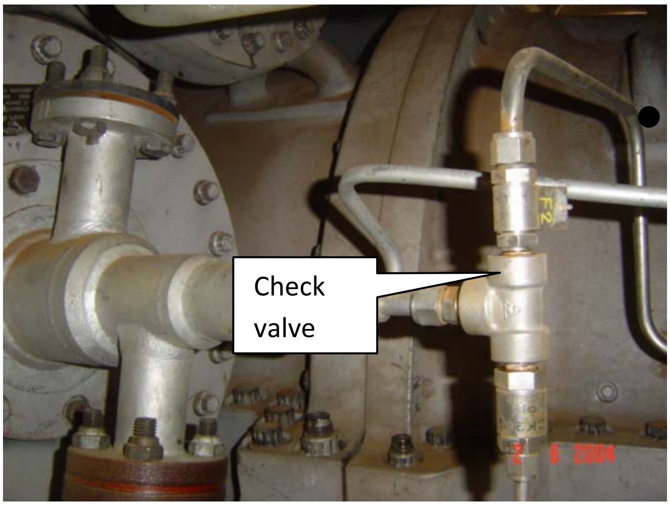
Flow divider pickups 77FD-1,77FD-2 and 77FD-3 pick up the flow divider speed signal which is the feedback signal in the outer control loop. The speed of the flow divider is the direct measure of the oil flow through it and to the turbine fuel nozzle in the combustion chambers.



88FM In the initial start-up flow divider is provided with a DC.

Fig 3.8 starting motor

Starting motor, this motor help to rotate the flow divider during the first moments of fuel oil injection in 5 seconds after ignition permissive.

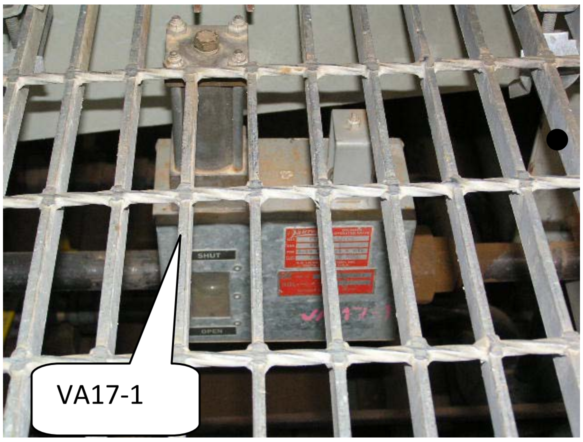


- **Check valves**

Check valve, one in each inlet piping ahead of fuel nozzles, prevent fuel oil from continuing to flow when a stopped signal is

Fig 3.9 fuel check valve

given. This result in a clean cut off of fuel to nozzles.

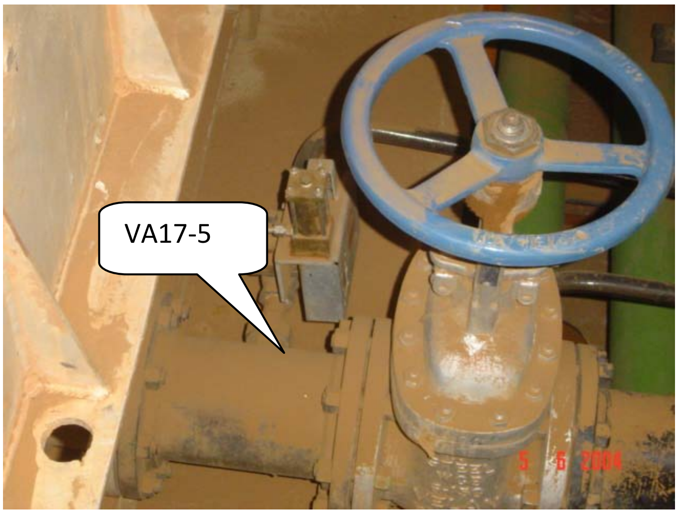


- **Drain valves**

In the event of an unsuccessful start, the accumulation of combustible fuel oil is drained through false start drain valves VA17-1 and VA17-5 into a special drain

Fig 3.10 false start drain

manifold. These valves normally open, close as the turbine accelerates, during turbine startup. Air pressure from the discharge of the unit's axial flow



the compressor is used to actuate these valves. During the turbine shutdown sequence the valve open as compressor speed drops (compressor discharge pressure is reduced).

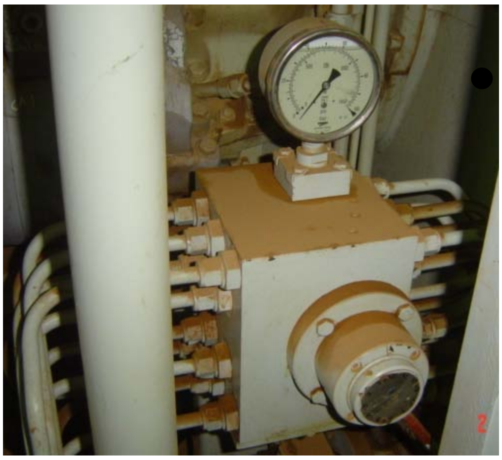
Fig 3.11 drain exhaust plenum

Valve VA17-1 drains excessive fuel from the combustion chambers, while valve VA17-5 drains the exhaust plenum.

- **VR27 Fuel oil pressure relief valve**

Fuel oil supply pressure relief valve setting at 10 bar to prevent overpressure at the line from forwarding pump to fuel oil stop valve.

Fig 3.12 fuel relief valve



- **Selector valve indicator**

A 12 position selector valve and pressure gauge assembly are located at the output of the flow divider to allow monitoring of selected fuel oil pressure in the nozzle inlet line. Position 1 through 10 select the fuel nozzle, position 11

Fig 3.13 selector pressure pump

selects the fuel pump inlet pressure, and position 12 select fuel pump outlet pressure

We need to add a new system of fuel may be doing some modification in the system add some part on the new one and check the feasibility of the new system.

3.4 Instruction Recommendation For Storage Of Liquid Fuel:-

Proper gas turbine operation is a dependent on a supply of clean fuel. The intent of this publication is to, furnish helpful information to those individuals responsible for the design, installation, and operation of a gas turbine liquid fuel system. Recommendations are included for reducing water and contaminants in "liquid fuels by proper design and maintenance of fuel storage facilities. Design and installation engineers and turbine operators are not limited in scope to the guidelines included here and may utilize any effective design or method that will attain the ultimate objective of a clean fuel system.

3.4.1 fuel

Liquid fuels, as received and after any type of treatment, shall meet the appropriate requirements specified in the Gas Turbine Division fuel specifications, publication GEI-41047.

The three basic fuel processing steps are listed below; however, it will be assumed in this publication that the fuel has been processed in accordance with instructions contained in Gas Turbine Division publication GEK-28153, which offers the detailed explanation of each.

1. Washing of fuel to remove any water-soluble harmful trace elements.

2. Inhibition of vanadium (V) by a magnesium compound.

3. Filtration

3.4.2 STORAGE TANK DESIGN

The number of fuel storage tanks and their size should be sufficient to provide a flow of fuel to the turbine(s) without interruption. A minimum of two storage tanks for each type of fuel is recommended. For example, an installation using both crude and distillate turbine fuels require at minimum four tanks; two distillate and two crude oil tanks. Each tank is to be of sufficient size so as to provide an UN_interirrupted supply of fuel for that period of time necessary to nil the second tank and allow a twenty-four hour settling period after f tiling.

If three tanks are used, each should provide sufficient fuel for twenty-four hours of operation. While fuel is being pumped from one tank, fuel in the second could be settling and the third tank could be in process of being filled.

It should be stressed that these are minimum recommendations; larger tank volumes provide a greater margin between switching of tanks.

With fuels which require washing, the use of a total certification tank is recommendeded. Washed and inhibited fuel goes to this tank first. It is sampled to verify that fuel treatment is satisfactory. Acceptable fuel can then be delivered to the main storage tank and unsatisfactory fuel may be rewashed. There may be instances, however, where another handling of unsatisfactory fuel is required.

Certification tanks prevent improperly washed fuel from contaminating a larger main storage tank. The size of the certificationation tank is determined by the specific operation and available manpower. A. tank which may be filled in eight hours is a reasonable size. After the tank is filled, the fuel quality is checked and acceptable fuel routed to the storage tank. While forwardin this fuel to the next station, consideration must be given to the fuel washing equipment since a period of time exists when the washed fuel has no place to go. Fuel washing system shutdown or a diversion of the washed fuel to the raw storage tank will then occur. Two certification tanks are recommended enabling continuous flow and keeping the washing equipment at the minimum size.

Initially, fuel being delivered to a storeage tank should pass through a screen or coarse filter to remove any large particles. Inlet piping to the storage tank should be eighteen inches (forty-six centimeters) minimum above the bottom of the tank. Baffling at the point of fuel entry is desirable. The incoming stream of fuel should not be directed toward the bottom of the tank or done in such a way as to stir up any material settled on the tank bottom. A velocity diffuser; shown in Figure I, can be used to minimize the jet effect of incoming fuel.

Use a floating suction in the fuel line to the turbine such as shown in Figure3.1, "Inlet Diffuser and Floating Suction". Limit the suction. Travel so that the inlet is never less than eighteen inches from the tank bottom.

NOTE:-

- Fuel must not be pumped from the bottom of the storage tank.

-Any recirculation of fuel back to a storage tank must be done in a manner that will cause minimum agitation of fuel in the tank. The return line should deliver the fuel at a location removed from the floating suction and in a way that will not stir up any material settled at the bottom of the tank.

3.5 STORAGE TANK OPERATIONAL MAINTENANCE

After filling a tank or adding additional fuel to it, allow a twenty-four hour settling period before taking fuel from this tank.

NOTE:-

Under no circumstance should fuel be pumped into a tank at the same time that it is being pumpeded out. Initially, drain water and any other sediment from storage tanks once per day. After experience has been established with a given fuel and fuel source, the frequency of draining may be decreased at the discretion of the operator. The water removed must be disposed of in a manner that meets local environmental regulations.

Storage tank bottoms should slope to an area from which water and other settled material can be removed. Three such configurations are shown on Figure3.2, "Tank Bottom Configurations".

Horizontal cylindrical tanks should be sloped at least two inches in ten feet (5 cm in 3 m) so that water will collect in one end where it can be removed by a sump pump or, if the tank is above ground, by a drain. If possible, a sump should be placed at the low end of the tank so that water removal can be complete.

For fuels that are highly volatile and have a low flash, point, it may be desirable to use a floating roof on the tank. This reduces the fire hazard and minimizes loss by evaporation. If used, there should be a fixed roof over the floating top designed so that there will be the minimum entrance of rain and condensation.

When tanks are intended to store high viscosity fuels, such as residuals, a means of heating must be provided to keep viscosity low enough so that the fuel may be pumped and water and other contaminants will set the-Cadmium, zinc, and copper catalyze the decomposition of hydrocarbons. These elements and their alloys, therefore, should not be used in the construction of storage tanks and related items.

After installation is completed, the inside of the tank and associated piping should be cleaned to remove any corrosion, weld slag or other contamination.

3.6 PUMPS

At most turbine installations, the pumps which deliver fuel to the turbine are provided by the General Electric Co. Should additional pumps be added to the system, each should have a sixty to one hundred mesh protective screen on the suction side with provision for removal for cleaning. Install pumps so that they are isolated by valves from the rest of the system thus simplifying removal for repair or replacement. Provide a pressure gauge on the outlet side of any pump. When the pumps are used with high viscosity fuels, the pumps and associated • lines should be heat traced and lagged.

2.7 SAMPLING

Representative samples should, *be* taken from incoming fuel shipments and analyzed for compliance with the applicable specifications. Though a detailed sampling plan is not given here, one should be prepared by the turbine user taking into consideration the means of delivery (pipeline, barge, tank truck, etc.) size of the shipment, and previous experience. The following are typical examples of things to be evaluated when preparing a plan.

a. A tank truck which repeatedly delivers to a given installation might require only periodic sampling whereas trucks making random deliveries should be sampled at each delivery.

b. Samples should be taken at different fluid levels in a large volume tanker or several samples taken from the line during the delivery process.

Any sampling plan requires that sampling points be included where necessary. These points should be included at the time of tank installation rather than trying to install them later.

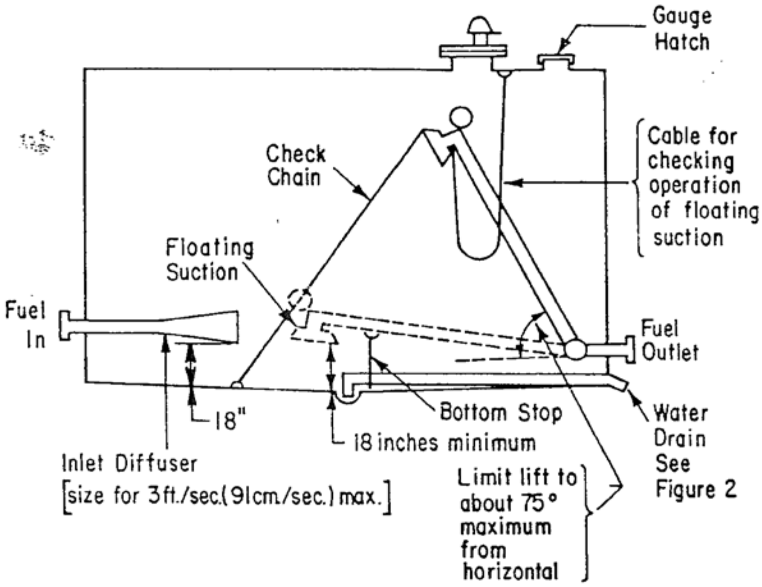


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Figure 3.14 inlet diffuser and floating suction

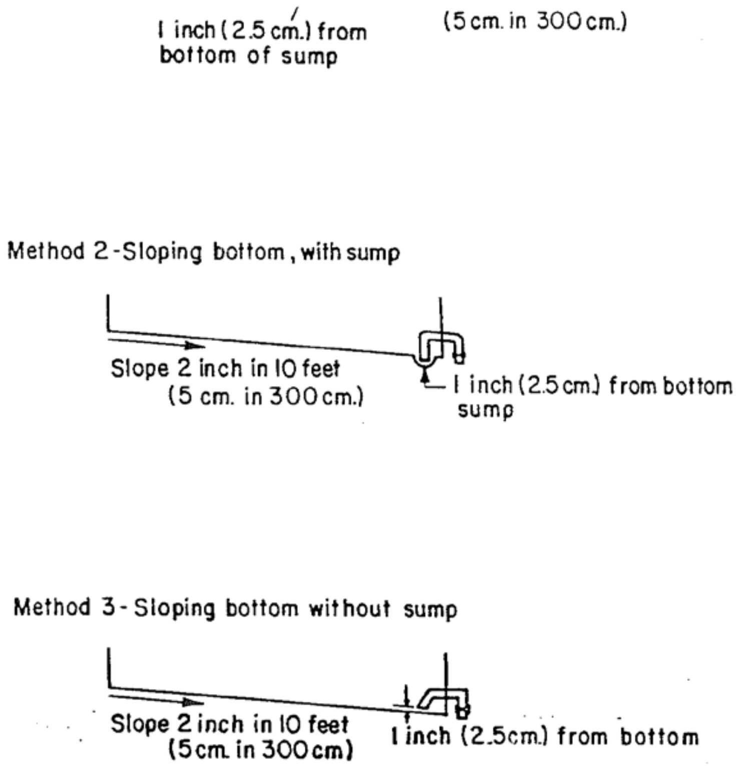

Fig3.15Method slope

Chapter 4

CALCULATION&EXPERIMENTAL

4.1 Description of system modification:-

According to the HCGO fuel analysis report (show all tables), of HCGO with low content of Na, K, V and Ash accord with gas turbine criterion and requirement for directly using, it does not need extra treatment system to clean these impurities. But for high viscosity oil under normal temperature, it is necessary to reduce its viscosity to meet the requirement of the gas turbine.

The modification divides into gas turbine body modification and forwarding system modification. The modification proposal of forwarding system is submitted here:

1-According to the requirement of the owner, change three of four existing LDO tanks into HCGO tanks. One of the three HCGO tanks needs to be added a heater. The insulation of the oil tank is unnecessary. The oil supply pipe and oil return pipe of HCGO need insulation

2- At present, the LDO pipeline from oil tanks to pump house adopts the dual main piping scheme. We plan to change it into a single main piping scheme. One pipe is for LDO, and another is for HCGO.

3-There are 6 sets of LDO pumps in pump hours now. Only 2 pumps are needed for the actual operation of 4 units. It is recommended to keep 3 sets of LDO pumps, two for use, and one for standby. The 3 dismantled pumps are kept as spare parts

4- Reinstall 3 sets of HCGO pumps on the basis of dismantled LDO pumps, two for use and one for standby. The purpose of this is to make the most use of pump house, so that the pump house does not have to be rebuilt and MCC cabinet also does not have to be added, just need to replace some components.

5-The LDO pipeline from the pump house to gas turbine adopts dual main piping scheme at present. One pipe should be kept for LDO oil supply; another is used for HCGO oil return. Add an extra pipe for HCGO oil supply

6-The source of heat for heating HCGO is bleeding steam from boiler high-pressure steam drum. Originally, it was used for hearing LPG. Connect a steam pipe from bleeding steam pipe to gas turbine head for heating HCGO, so that the HCGO can be met requirement of gas turbine

7- The heat exchange skid, filtration skid and switching skid of HCGO are placed on the right of the gas turbine, besides existing forwarding filter skid. The modularization design can shorten the construction schedule on the site.

8- Set an oil return tank for HCGO flushing beside existing waste oil pool and pump the oil back to HCGO tank. The oil tank should be set underground for oil return.

9- Merge the control system of HCGO pumps into ABB control system.

Table (4.1):- fuel analysis HCGO

فوكس لتصنيع الزيوت و الشحوم

Fuchs Lubes & Greases Factory

FUCHS

TEST REPORT

Sample : HCGO
Customer : NEC
Test : Metal Content
Test Method : ASTM D - 4951 ICP

Date : 03.01.11
Sample Receiving Date : 02.01.11

Metal	Test Unit	Test Result
Vanadium V	mg / Kg (ppm)	2.23
Nickel Ni	mg / Kg (ppm)	3.9
Iron Fe	mg / Kg (ppm)	0.11
Calcium Ca	mg / Kg (ppm)	0.13
Copper Cu	mg / Kg (ppm)	< 0.10
Magnesium Mg	mg / Kg (ppm)	0.061
Sodium Na	mg / Kg (ppm)	< 0.10
Zinc Zn	mg / Kg (ppm)	0.15

Abdel Latif Ahmed Mohamed Ahmed
Quality Control Manager

03.01.11

Petrob sh M.A. Co. Ltd
فوكس

FUCHS

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Tel:+249155770456
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Fax:+249 183 741490
URL: www.fuchs.com.sd

Sales & Customer Service
P.O. Box 4220
Khartoum, Sudan.
Tel:+249 183 741486
Fax:+249 183 741493
Email: sales@fuchs.com.sd

Table (4.2):- fuel analysis HCGO from KRC

Page 1 of 1

Khartoum refinery Co. Ltd.
Central Laboratory

شركة مصفاة الخرطوم

Add: Khartoum North, Geili Town, Sudan Tel:00249-185-350000-8331 Fax:00249-185-350667

Test Report No. : 82-11

Customer: Sudanese Petroleum Corporation

Product Heavy coker gas oil

Tank No. 87003

Date Sampled 2011.01.23

Sample No. 05-230111-H03

Analysis Date 2011.01.23

Distribution ☐ Central Lab ☑ Dispatch Center ☐ OMS

Properties		Specification	Results	Test methods
Density at 15°C, kg/m³	max	990.0	902.0	ASTM D1298
Flash point, °C	min	60.0	87.4	ASTM D93
Water, %mass	max	0.75	0.03	ASTM D95
Strong Acid Number,mgKOH/g	/	Nil	Nil	ASTM D974
Pour point, °C	max	25	16	ASTM D97
Kinematic viscosity at 100°C, mm²/s	max	25.00	3.984	ASTM D445
Ash, %mass	max	0.150	0.010	ASTM D482
Sulfur, %mass	max	3.00	0.104	ASTM D4294
Carbon residue, %mass	max	10.0	0.02	ASTM D4530

Monitor	Name: Zhongzhili	Lab Manager	Name: Feng Donghong
Remark		Issued date:	2011.01.23

Note: This test report contain 9 results and shall not be reproduced except in full, without written approval of the laboratory.

Table (4.3):- HCGO properties

The following sample(s) was/were submitted and identified by client as:

Sample Description : Heavy Coked Gas Oil
Sample No. : 2009321
Sample Condition : Contained in glass bottle and kept at room temperature.
Mark / Reference : H.C.G.O Sample

Date Received : 7-Feb-2011 Date Commenced : 7-Feb-2011

Test Items	Method	Results	Units
Vanadium (V)	ASTM D 5185-09	Less than 0.10	mg/kg
Nickel (Ni)	ASTM D 5185-09	Less than 0.10	mg/kg
Iron (Fe)	ASTM D 5185-09	0.11	mg/kg
Calcium (Ca)	ASTM D 5185-09	Less than 0.10	mg/kg
Copper (Cu)	ASTM D 5185-09	Less than 0.10	mg/kg
Magnesium (Mg)	ASTM D 5185-09	Less than 0.10	mg/kg
Sodium (Na), Potassium (K)	ASTM D 5185-09	Less than 0.30 /ea	mg/kg
Zinc (Zn)	ASTM D 5185-09	Less than 0.10	mg/kg
Density at 15 deg C	ASTM D 4052-09	0.9091	g/cm3
Flash Point	ASTM D 93-10a (Procedure B)	101.0	degree C
Water Content	ASTM D 6304-07	0.03	% wt
Total Acid Number	ASTM D 664-09a	1.15	mgKOH/g
Pour Point	ASTM D 97-09	-3	degree C
Kinematic Viscosity at 100 degree C	ASTM D 445-10	4.038	mm2/s
Ash Content	ASTM D 482-07	Less than 0.001	% wt
Sulphur Content	ASTM D 4294-10	0.110	% wt
Carbon Residue	ASTM D 4530-07	0.40	% wt

4.2 Description of Garri 1 HCGO Upgrading:-

For using HCGO, the systems below must be added:

A. HCGO PURGE

Because the gas turbine cannot use HCGO for igniting. A set of purge valves must be

installed for draining the remaining HCGO and flushing the fuel oil piping after a gas

turbine trip on load with HCGO. The purge program will start up automatically and purge piping after a trip until the fuel line contains100% of diesel. A sight glass

allows a visual check.

The purge valves involve a 10 ways hydraulic valve VP1 with the position switch, control

solenoid valve 20PF-100, control button 43FUOP, new hydraulic oil piping, and new

drain piping. New drain tank and the new pump are necessary to reuse the drain oil.

B.OTHER PART

New high-pressure atomization air pump, new fuel flow divider, new filter cores and

other equipment must be changed to meet the requirement of the gas turbine using HCGO.

Because the viscosity of HCGO is high, it is prone to block the filter and flower

divider and difficult to be atomized.

C.HCGO SUPPLY SYSTEM

- HCGO FORWARDING PUMPS

The HCGO pumps skid supplies fuel oil with sufficient pressure to overcome the

the pressure drop of the various components from the oil tank to the GT inlet and meet

the pressure requirement of GT.

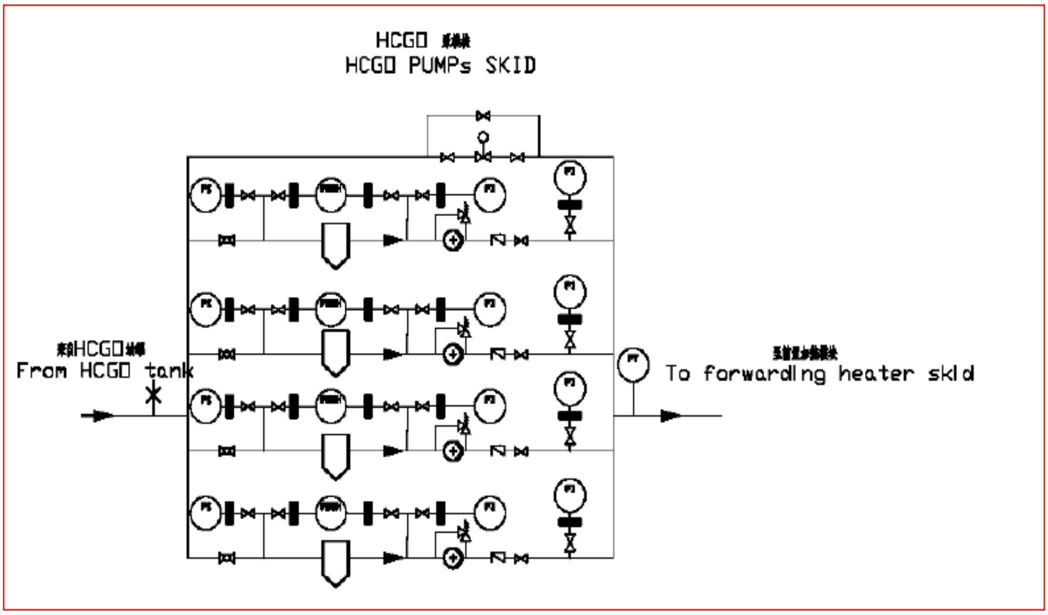


Fig 4.1 HCGO forwarding pumps module sketch

D. FORWARDING HEATER MODULE

Heater skid heats the HCGO to reduce its viscosity to easy atomize and combust. It

mainly includes 2 plate heat exchangers（1 operate, 1 standby）and 1 temperature

control valve to make HCGO reach proper temperature.

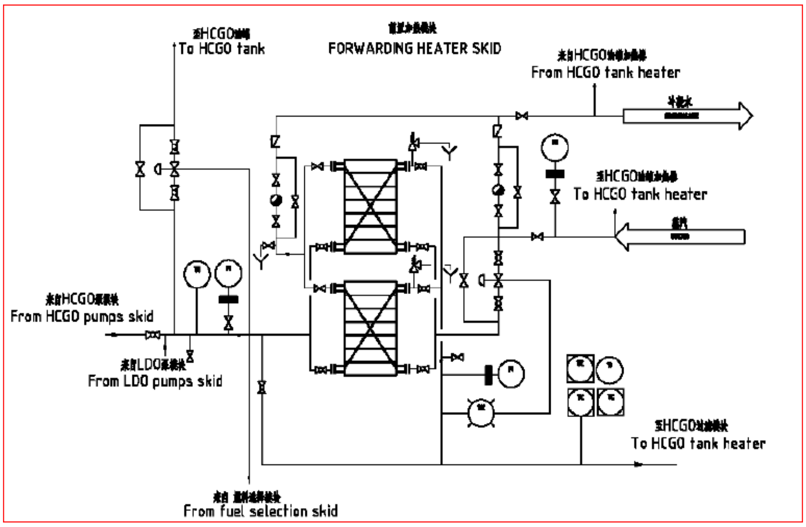


Fig 4.2 HCGO forwarding heater module sketch

E.HCGO FILTER MODULE

This module can filter the HCGO and make it reach the cleanliness requirement of

liquid fuel specification GEI-41047.

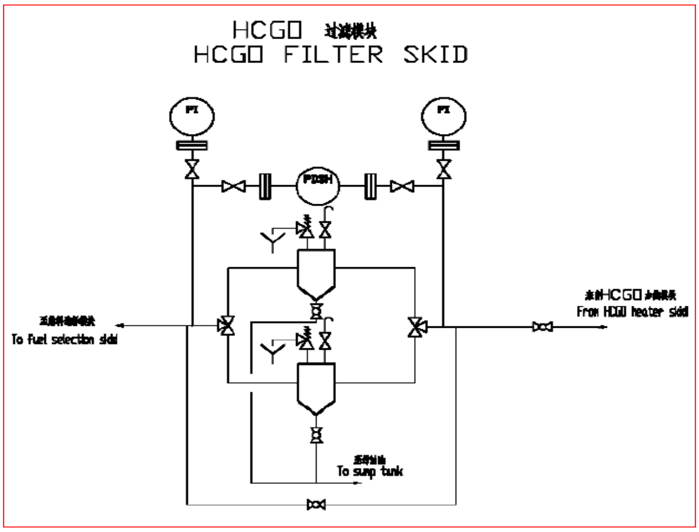


Fig 4.3 HCGO filter module sketch

F. FUEL SELECTION MODULE

This skid controls fuel selection. When GT start up, fuel switch valve is on LDO

position. As the load of GT rises to the switch load, the switch valve slowly change to

HCGO position (if choose HCGO mode in MARK V). After about 10 minutes, the

switch valve is totally on HCGO position. When GT shuts down and loads reduction to

the switch load or HCGO fuel faults, the switch valve quickly changes to LDO position.

When GT trip with HCGO, the two pneumatic stop valves close immediately, switch

valve changes to LDO position. In the following purge program, pneumatic stop valve

of LDO piping will open to cooperate with HCGO purge valve VP1 complete purge

program.

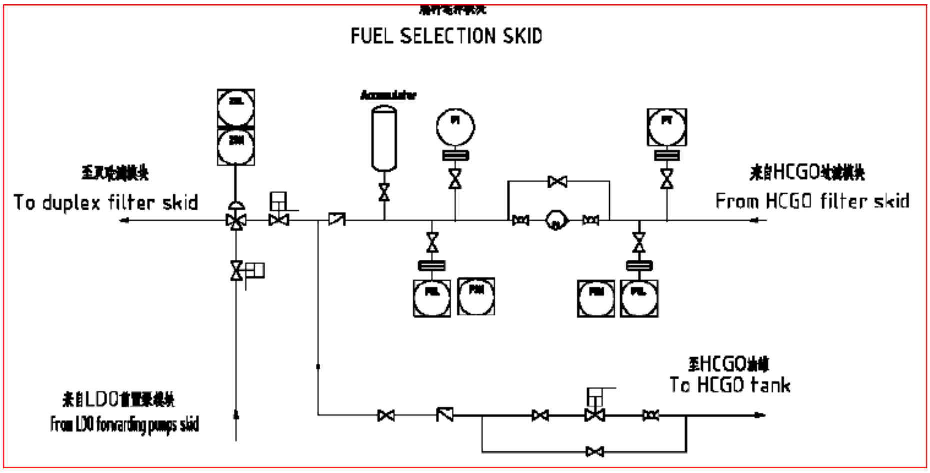


Fig 4.4 Fuel selection module sketch

The filtration skid can filtrate and measure HCGO and switch between HCGO and

LDO (LDO→LDO and HCGO→HCGO) The liquid fuel pressure at GT inlet must be

between 2,75 bar g and 5,17 bar g.

These modules make the liquid fuel obtain the requirement of GT in the respects of flow, pressure filtration, and viscosity.

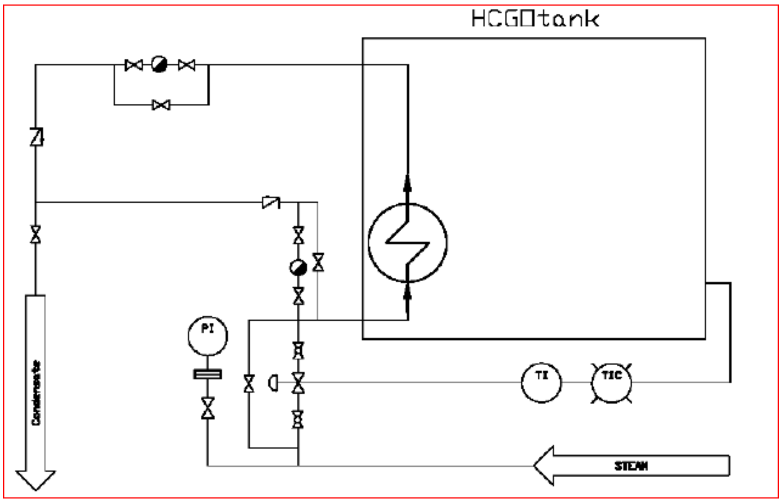


Fig 4.5 HCGO tank heater sketch

4.3 **Calculation:**-

All data collected from the garri1,2 power station, department off efficiency and planning, monthly reports.

-fuel comparison is between (LDO, HCGO).

-Averages are taken for one block by dividing by 4.

- Estimated base load for each block 90 MW(each block consists of 2GT unit and 1 ST unit)

-a load calculation is a base on 24 hours a day 320 for 1 year (subtract 45 days for maintenance work)

- 1 Block =30 MW * 3 unit * 24 hours * 320 days =691200MW output

Auxiliary power consumption average calculated = 2.538 % of the total generated load.

Total sent energy= 691200-(691200*0.02538)=673657 MWh

-Fuel consumption calculation (for LDO and HCGO) are base on 9 ton/hr on base load.

-1 block consumption = 9(ton/hr)*2(GT unit)*24(hour)*320(day)= 138240 ton/year (45 days for maintenance)

-KW.hr price (SDG/KW.hr)= total cost/ Actual sent energy

-Auxiliary consumption = 0.02538*691200= 17543 MW

Total cost (operation cost , maintenance cost, fuel cost , depreciation cost , insurance ,density LDO=1.215

Fuel price are (2179.481 SDG/ton for LDO ,331.32 SDG/ton for HCGO)

Maintenance cost is increased by10%,20%,30%,40%,40% and 50% to meet modifications,maintenance work

Consumption per block: according to fuel (furt ,oil .weadage to ....)

- ✧ Operational cost using (LDO)=consumption LDO price= 138240*2179.48=301291315.2 SD
- ✧ Operational cost using (HCGO)= consumption HCGO price= 138240*331.32= 45801676.8 SD

- **Operational cost saving between (LDO) and (HCGO) = 301291315.2 - 45801676.8 = 255489638.4 SDG/year**

Kw.h price according to fuel=cost of fuel*consumption fuel / total sent energy

For :

1- LDO

Kw.h price=301291315.2 / (673657 *10^3) = 0.44725 SD/kw.hr

2- HCGO

Kw.h price= 45801676.8 / (673657 *10^3) =0 .067989 SD/kw.hr

- Efficiency η= total output / input

- For LDO per block

$\eta_{LDO=}$ = 90*3600/(45500*18)= 0.395≈0.40

- Heat rate$_{LDO}$=1/η = (1/0.40)*3600= 9000 KJ/kw.h

- For HCGO per block

$\eta_{HCGO=}$ = 90*3600/(44000*18)= 0.4090≈0.41

-- Heat rate$_{HCGO}$=1/η = (1/0.41)*3600= 8780.484 KJ/kw.h

4.4 Use Ansys program to analyses:-

Advanced GE materials are paving the way for dramatic improvements in gas turbines —improvements that are setting new records in giving customers the most fuel-efficient power generation systems available. Combined-cycle efficiencies as high as 60% are now achievable

because of increased firing temperature coupled with more efficient component and system designs. Ongoing GE developments now

promise that the coming decade will witness continued growth of gas turbines with higher firing temperatures, pressures, and outputs.

This paper describes the evolution of solutions to what used to be incompatible market demands: high firing temperatures and long

life, corrosion protection from contaminated fuels and air, and higher efficiency with fuel flexibility. It concentrates on advances made in

the hot gas path components because they are generally the most critical part of the gas turbine. Improvements in superalloys and processing

now permit the hot gas path components to operate in advanced gas turbines firing at increased temperatures for many thousands

of hours under severe conditions of centrifugal, thermal and vibratory stresses. Recent improvements to compressors and rotors are

also discussed. GE engineers continue to lead the way in understanding and developing materials technology for gas turbines because they can tap knowledge from the laboratories of one of the world's most diversified companies, with products ranging from aircraft engines to high technology plastics. They have used these resources and data collected from more than 5,000 gas turbines operating in many climates,

and on a wide range of fuels, to verify that the materials will perform under demanding conditions.[9]

4.5 Result:-

After use Ansys programme obtain

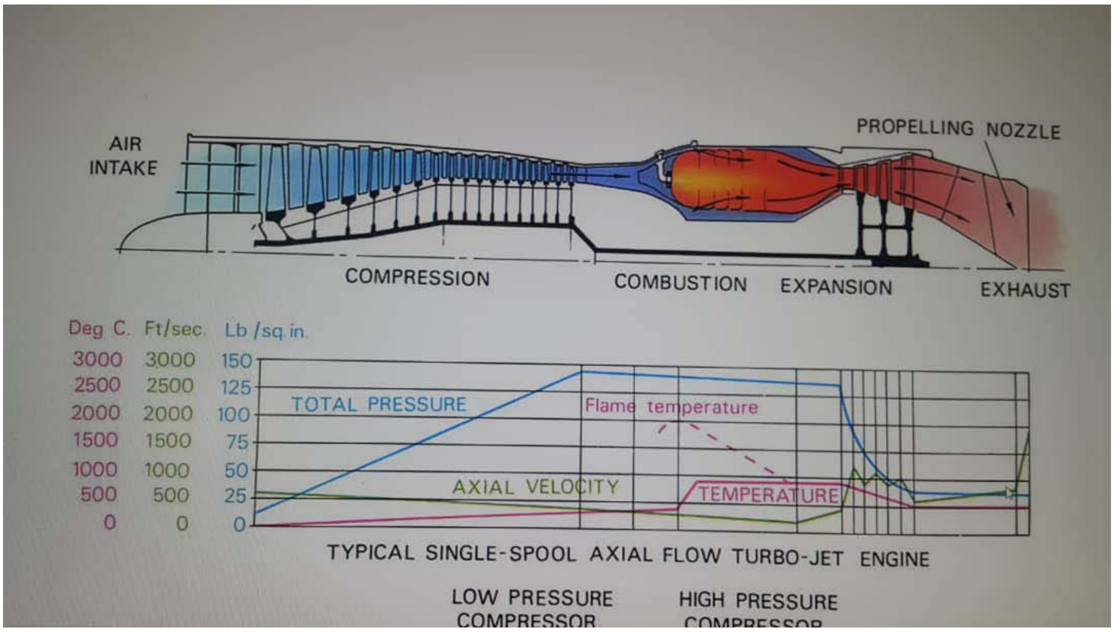


Fig 4.6 Gas turbine section

- General static force structural for gas turbine compressor side and turbine side general form stress max in stop shaft this result reaction for direction flow

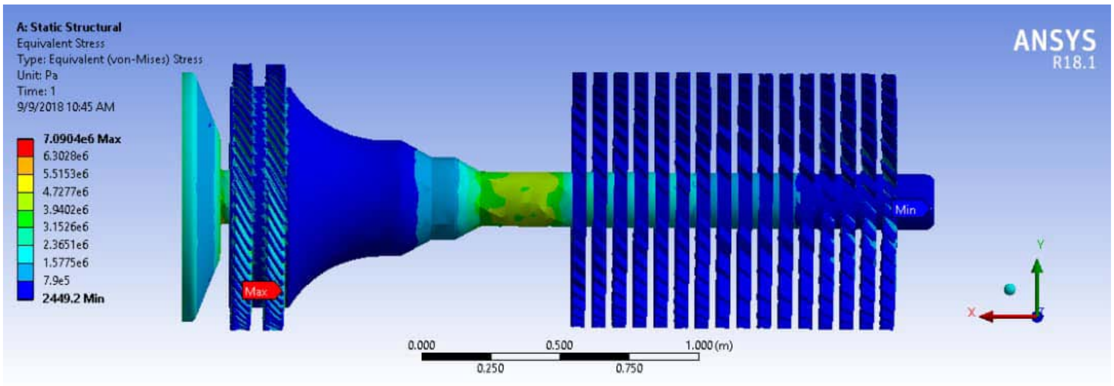
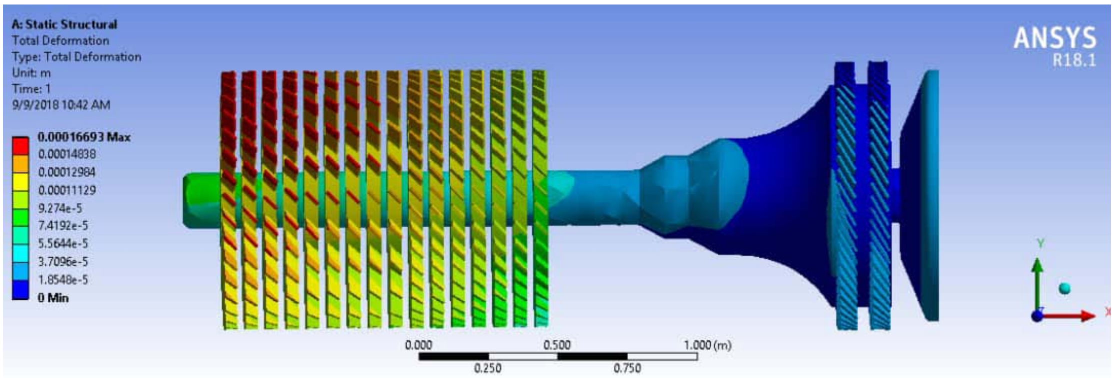


Fig 4.7Gas turbine use Ansys program static structural



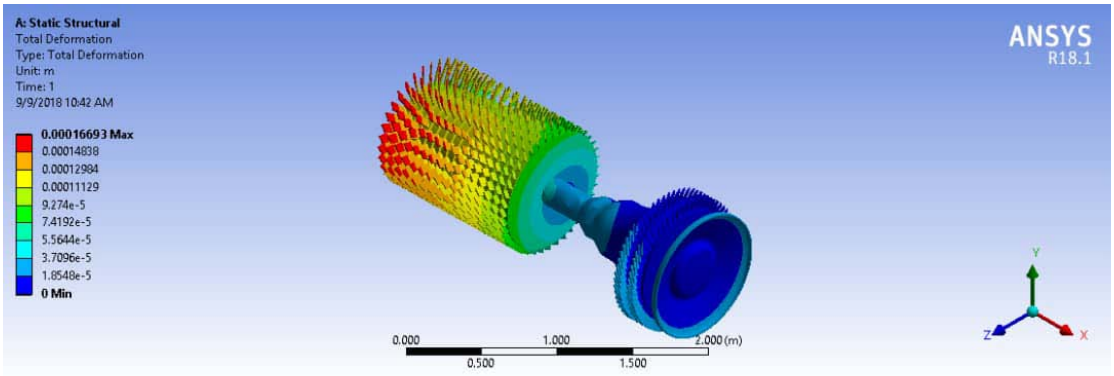


Fig 4.8 total deformation

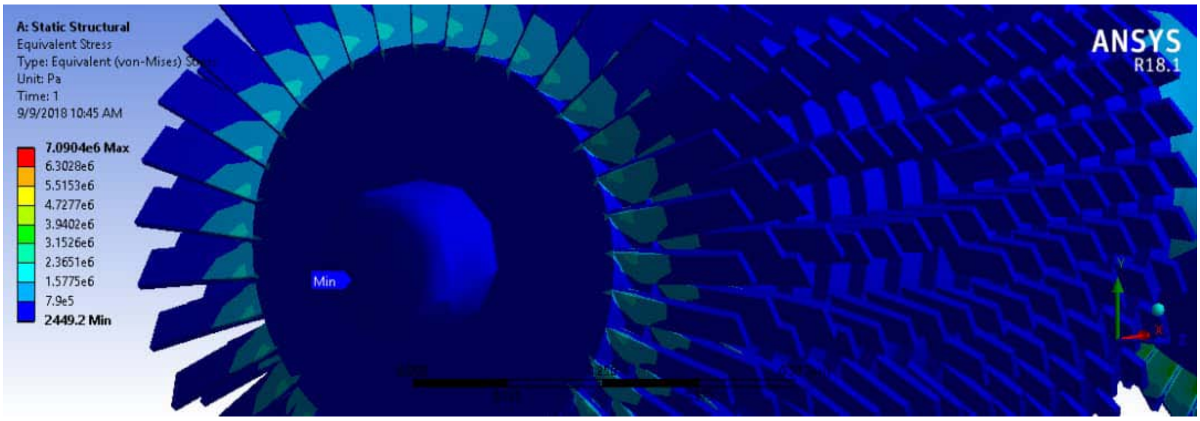


Fig 4.9 stress in the compressor side

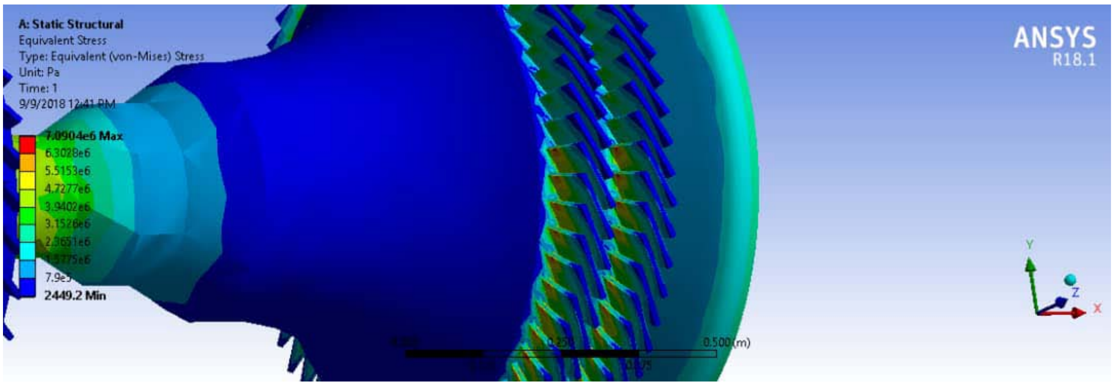


Fig 4.10 stress in turbine side (front) effect area

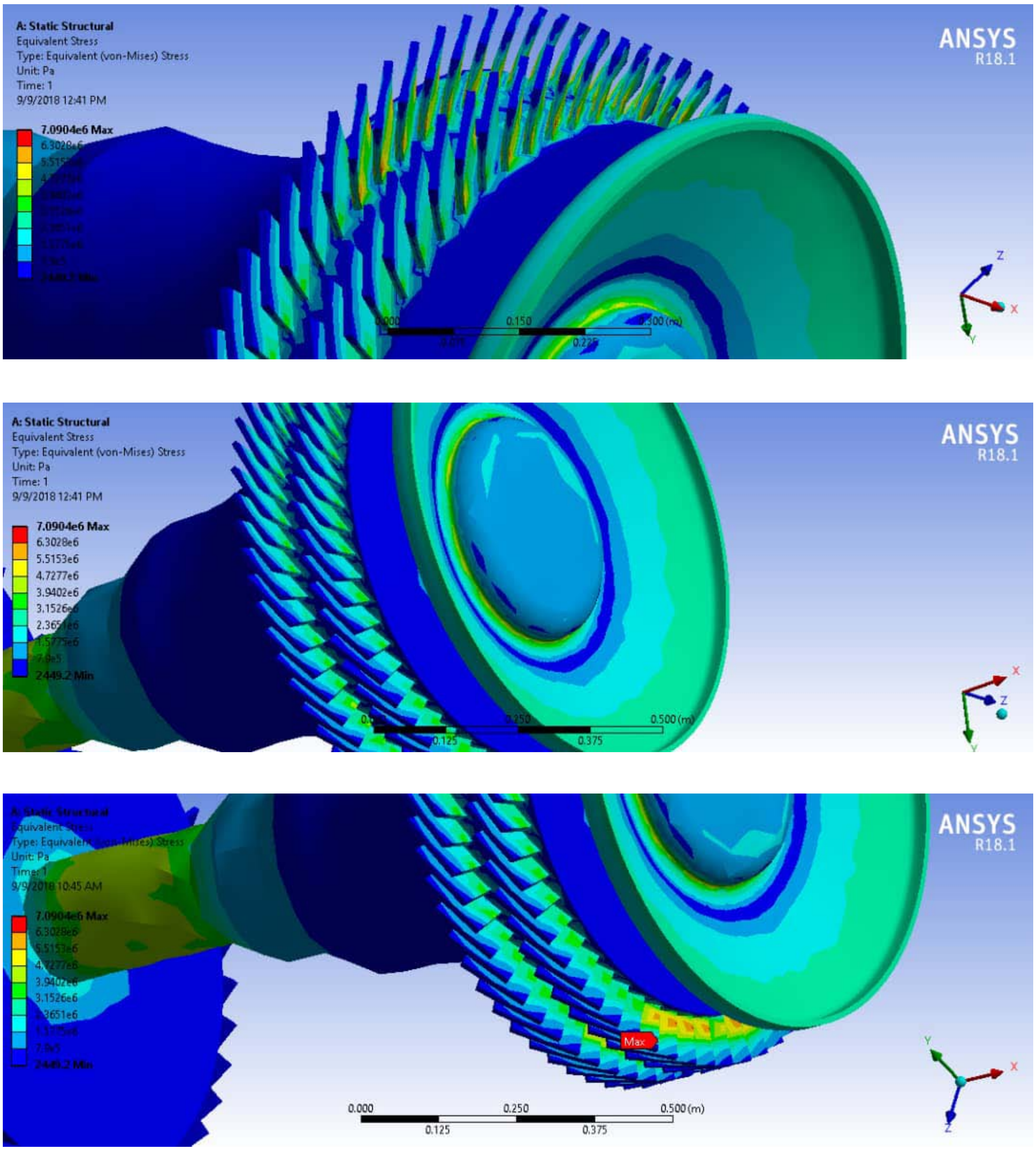


Fig 4.11 stress in turbine side (behind) after analyzing

Comment:=

- General static force structural for gas turbine compressor side and turbine side general form stress max in stop shaft this result reaction for direction flow. (fig 4.4&4.5).

- Form figure (4.5 &4.6) side effect on bucket we can see clearly and this effect same actual inside maximum stress and heating, this heat
- different for fuel to each other according to radiation and caloric value, density, and specification of fuel.

4.6 Actually inside after use HCGO fuel:-

Fig 4.12 first stage bucket blade and tip actually effect.

Fig 4.13first stage nozzle actually effect

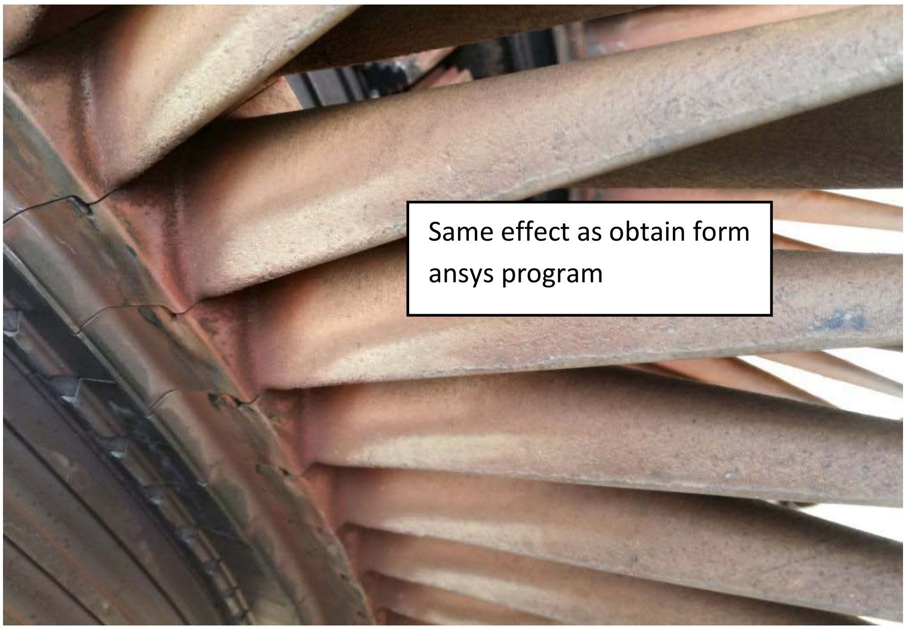


Fig 4.14second stage bucket effect actually same as obtain form Ansys program

Fig 4.15 third stage bucket actually effect on the profile

Fig 4.16 gas turbine section three stage

Fig 4.17 heat recovery steam generation working by HCGO (exhaust)

first time inspection

Fig 4.18 superheated pipes working by HCGO

4.7 Discussion:

Through the results obtained by ANSYS Fluids program and photo form exhaust gas turbine to analyze them and show a condition of bucket and heat recovery steam generation was obtained as follows:

First, other of hand about visibility different price between HCGO and LDO (HCGO less than LDO) farther more this fuel it is residues from Khartoum refinery not use for everything

from Another side of view about effects on the bucket when we apply velocity about (500 ft/sec = 152.400 m/sec) and force about 500 KN, and temp=1200^{O}C, pressure 10 bar, we found an effect on to side:-

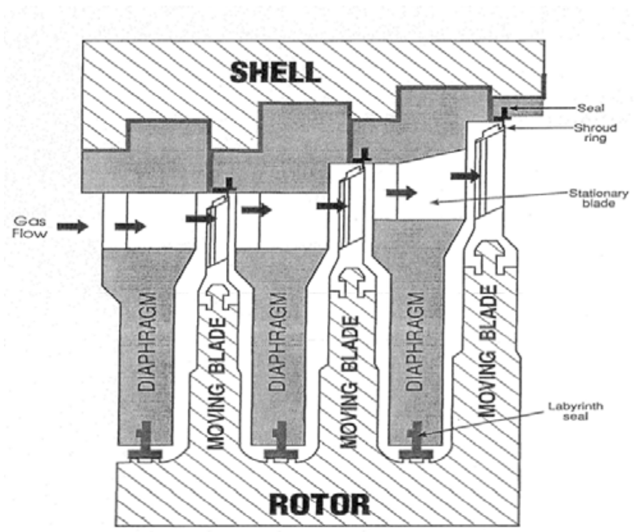


Fig 4.19 turbine blades and seal

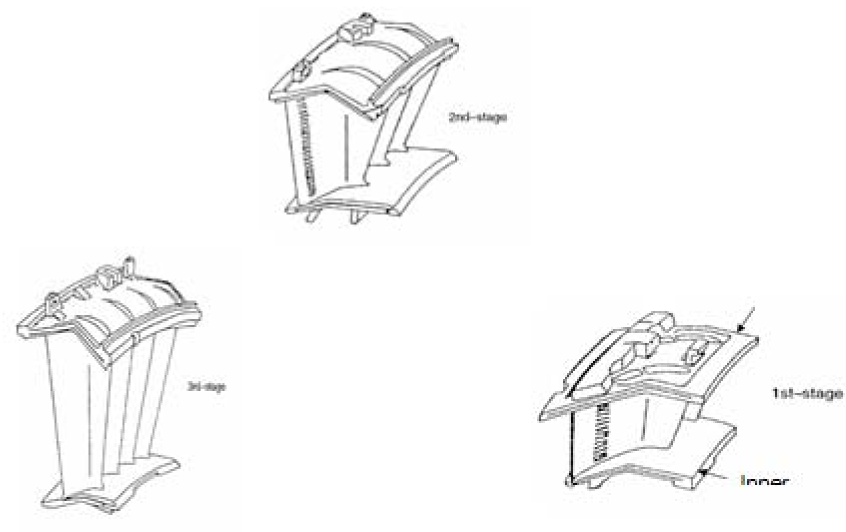


Fig 4.20 nozzle of a gas turbine

Firstly on the profile of bucket and nozzle tip and root of the bucket on the suction side.

Note:- *(About bucket needs more or advance inspection we can do outside of Sudan in special workshop use advance inspector machine to the final report.)

And also expected the effect on liner according to high radiation for fuel and temperature, because this fuel it distilled fuel or last phase form refinery, and it contains residues and impurities.

According to specification of fuel (HCGO) in chapter four about viscosity (viscosity @40^{o}c = 14.6 from target 17.14) when use it , the part use Flow divider(distribute fuel equally form combustion chamber) need flashing by (L.D.O) to prevent stuck with gear (when shutdown suddenly or trip) make it works not properly, may be effective on spread temperature in exhaust of gas turbine causes trip gas turbine.

Other of hand we found more ash and CO_2 in HRSG should be effective in heat transfer on HRSG.we can do soot blower to avoid ash form pipe every shutdown can start.

Fig.5.1 First, second and third stage gas turbine deposit effect by HCGO

Chapter 5

Conclusion & Recommendations

5.1 Conclusion:

Use new fuel (**HCGO**) in garri power station we can get the highest benefit because it decreases the operational cost by about 78 % when compared with the base case.

- The feasibility is high scored due to the kW.hr price which decreases from 0.44725 SDG to 0.067989 SDG.
- Other of hand use new fuel that implies availability LDO use vehicle and industrial.
- Better to use new technology in the bucket and nozzle of the turbine about quoting and advance material.
- Use soot blower in heat recovery steam generation (HRSG) to avoid co_2 accumulated around the pipe at HRSG.
- Same effective results area inside turbine obtain after use any programme(need more check-in the external workshop)

The weak point in this option is in the risks, especially in the continuity of fuel oil from KRC.

5.2 Recommendation:

Gas turbine water wash is carried out to remove the deposit from HCGO when the unit is cold and needs to operate water wash valves by hands like compressor water wash.

It has to add new turbine water washing motor valve and new piping. The new piping connects to original water washing skid.

- And also duration normal operation when we change filter and replacement... don’t fill again let up to need to use it.
- Soot blower need to be installed to remove the ash form heat recovery steam generation
- Select new spare part upgrade material and quoting bucket and combustion chamber.
- Biro scope inspection time to time to check inside the turbine.
- Make a system to return water to the system again after heating HCGO
  To reduce losses

Reference:

[1] Fuel Gases for Combustion in Heavy-Dig Gas Turbines G.E. 41040F Revised January 1999

[2] Garri power station

[3] IGCC Gas Turbines for Refinery Applications Robert M. Jones Norman Z. Shilling GE Power Systems Schenectady, NY 12345

[4] Gas turbine fuel evaluation process: A case study on the application of Arabian Super Light Crude Oil for use in GE 7F-class Dry Low No_x (DLN) combustion systems.

[5] Fuel-flexible, efficient generation using internal combustion engines (ICEs) to meet growing demand in Myanmar POWERGEN ASIA 2015 M. Raja go palan, Market Development Director, Middle East, Asia & Australia Power Plants, Watseka India Pvt. Ltd. Stuti Gandotra, Market Development Analyst, Middle East, Asia & Australia Power Plants, Wärtsilä India Pvt. Lt.

[6] FUELS FLEXIBILITY IN HEAVY-DUTYGAS TURBINES

A.D. Foster, H.E. von Doe ring, and M.B. Hilt

GE Company Schenectady, New York

[7] Addressing Gas Turbine Fuel Flexibility ,GER4601 (06/09)

[8] Document at garri power station