CONTENT

ABSTRACT

Explanatory note to the diploma project **"Investigation of ways for improvement of compressor stations work in Nigeria State"**: 94 pages, 22 figures, 10 tables, 13 used sources.

Key words: Gas Turbine Plant (GTP), Gas Compressing Unit (GCU), Compressor Station (CS), Ambient Temperature, Ambient Pressure, Capacity Estimation, Heat Transfer, Pipeline, Humidity, dustiness of atmosphere.

Research object is about atmospheric conditions of Nigeria states and its influence on technical state of compressor Stations equipment.

The aim of diploma work – providing of reliability work of all equipment of gas transport system.

Research method: analysis of climatic characteristics and learning of different influences of climatic peculiarities at equipment technical state with help of mathematical models.

Materials of diploma work are recommended to be use at CS reconstruction with the aim to improve technical state of gas transport system equipment.

LIST OF CONVENTIONAL ABBREVIATIONS, DESIGNATIONS, SYMBOLS

In given part is given the main list of designations, which are used in equations of diploma work and also main terms, which are used in text explanations.

Key words – by capital letters in abstract:

GCU – gas compressing unit;

GTP – gas turbine plant;

GTE – gas turbine engine;

CS – compressor station;

LPC – low pressure compressor;

HPC – high pressure compressor;

HPT – high pressure turbine;

LPT – low pressure turbine;

FT – free turbine;

WW – working wheel;

AGTE – aviation gas – turbine engine;

$T_н$ – standard temperature;

$P_н$ – standard pressure;

R – gas constant;

k – adiabatic index;

Other designations and terms are explained in diploma project.

NOMENCLATURE

Hm	-	Burial depth (from center of pipe to sea floor)
$W/(m^2 K)$ H_o	-	Inner heat transfer coefficient
$W/(m^2 K)$ k_{gas}	-	Outer heat transfer coefficient
$W/(mK)$ k_n	-	Thermal conductivity of gas
$W/(mK)$ k_{sea}	-	Thermal conductivity of wall layer n
$W/(mK)$	-	Thermal conductivity of sea water
K_{soil} $W/(mK)$	-	Thermal conductivity of soil
N	-	Number of wall layers
Nu	-	Nusselt number
Pr	-	Prandtl number
QW	-	Heat transfer
R_i m	-	Inner radius of pipe
r_n m	-	Radius of wall layer n
r_o m	-	Outer radius of pipe
T_{amb} K	-	Ambient temperature
T_{gas} K	-	Gas temperature
U $W/(m^2 K)$	-	Overall heat transfer coefficient
U_{ground} $W/(m^2 K)$	-	HTC* contribution from soil
$U_{sea}W/(m^2 K)$	-	HTC* contribution from sea water
U_{total} $W/(m^2 K)$	-	Total heat transfer coefficient
U_{wall} $W/(m^2 K)$	-	Heat transfer coefficient for pipeline wall

*HTC = Heat transfer coefficient

INTRODUCTION

Contemporary state of Nigeria gas transportation system require updates, as majority of compressor stations are equipped with gas turbine plants manufactured more than 25 years ago. New GTP should be more effective, easier for maintenance and should be more reliable in operation. However tendencies in development of such drives attended by the considerable increasing of thermal and dynamic loadings on the construction components and initiation of new problems during it operation.

The aim of this diploma work is to increase the exploitation reliability of all equipments which are used in gas transport system in Nigeria. Which work in harsh climatic condition such as high ambient temperature and moisture.

In part 2, influences of different climatic conditions at compressor stations working plant in Nigeria was considered. The effect of ambient temperature on pipelines, changes in output performance at different climatic conditions. In addition, effect of ambient dust on aggregates was researched.

In part 3, different measures are taken into consideration in order to improve the technical state of aggregates at compressor stations in Nigeria effect of climate conditions on aggregates. Modelling methods such as Turbomatch and Pythia was used to analyze and estimate the performance of the aggregates when different ambient temperature and pressure is in consideration.

In part 4 the main items of labour precaution in specialty, causes of harmful and dangerous factors of subject of labour precaution are considered, to carry out methods decreasing harmful and dangerous factors of subject of labour precaution, main standards and enforcement for evaluation and control requirements and also analyses fire and explosive safety are proposed.

Part 5 deals with ecological problem of compressor stations in Nigeria, such as noise emission, air quality, hazardous materials and waste and methods for protecting the environment.

PART 1
CLIMATIC PECULIARITY IN DIFFERENT REGIONS OF NIGERIA.

1.1. Brief information about Nigeria.

Nigeria is a nation in West Africa. Nigeria shares land borders with the Republic of Chad and Cameroon in the east, Benin in the west, and Niger in the north. Its coast lies on the Gulf of Guinea in the south and it territories Lake Chad to the northeast. Noted geographical topographies in Nigeria include the Adamawa highlands, Jos Plateau, Mambilla Plateau, the Niger River, Obudu Plateau, River Benue and Niger Delta. [11]

Nigeria is located in the Tropics, where the climate is seasonally damp with high humidity. Nigeria is have four climate types; these climate types are distinguishable, as one moves from the southern part of Nigeria to the northern part of Nigeria through Nigeria's middle belt.

Fig. 1.1- Map of Nigeria

1.2. Types of Climate found in Nigeria

The tropical monsoon climate, titled by the Köppen climate classification as "Am", is located in the southern part of the country. This climate is influenced by the monsoons originating from the South Atlantic ocean, which is brought into the country by the (maritime tropical) MT air mass, a warm moist sea to land seasonal wind. Its warmth and high humidity gives it a strong tendency to ascend and produce copious rainfall, which is a result of the condensation of water vapour in the rapidly rising air. [16]

The Tropical monsoon climate has a very low temperature range. Then temperature ranges are almost constant throughout the year, for example, Warri town in the southern part of Nigeria, records a maximum of 29°C (82.4 °F) for its hottest month while its lowest temperature is 27 °C (78.8 °F) in its coldest month. The temperature difference of Warri town is not more than 2 °C (5 °F).

The southern region of Nigeria experiences a twice rainfall maxima characterised by two high rainfall peaks, with a short dry season and a longer dry season falling between and after each peaks. The first rainy season starts around March and last to the end of July with a peak in June, this rainy season is followed by a short dry break in August known as the August break which is a short dry season lasting for four to three weeks in August. The ending of the short rainy season in October is followed by long dry season. This period starts from late October and lasts until early March with peak dry conditions between early December and late February. This break is broken by the short rainy season starting around early September and lasting to mid-October with a peak period at the end of September.

The southern part of Nigeria experiences heavy and plentiful rainfall. These storms are usually convectional in nature due to the states proximity, to the equatorial belt. The yearly rainfall received in this region is slightly high, usually above the 2,100 mm (78.7 in) rainfall totals giving for tropical rainforest climates worldwide. About 4,100 mm (157.5 in) of rainfall is received in the coastal region of Nigeria around the Niger delta area. Bonny town found in southern Nigeria in the coastal region of the Niger delta area receives well over 4,100 mm (157.9 in) of rainfall per annum. The rest of the southeast receives between 2,100 and 3,100 mm (118.8 in) of rain per annum. [11]

The tropical wet and dry climate or tropical savanna climate, is extensive in area and covers most of western Nigeria to central Nigeria beginning from the tropical rainforest climate boundary in the central part of Nigeria to southern Nigeria, where it exerts enormous influence on the region.[16]

This climate, the tropical savanna climate shows a well-marked rainy season and a dry season with a single peak known as the summer maximum due to its distance from the equator. Temperatures as high as above 19 °C (65 °F) throughout the year. Abuja, Nigeria's capital city found in central Nigeria, has a temperature between 19.45 °C (65.21 °F) to 37.9 °C (99.4 °F), and an annual rainfall of approximately 1,550 mm (60.1 in) with a single rainfall maxima in September.

The only dry period experienced in this climate, the tropical savanna climate in central Nigeria start from December to March, is hot and dry with the Harmattan wind, a continental tropical air mass laden with dust from the Sahara Desert prevailing throughout this period.[17]

With the Intertropical Convergence Zone swinging northward over West Africa from the Southern Hemisphere in May, heavy showers coming from pre-monsoonal convective clouds mainly in the form of squall lines also known as the north easterlies formed mainly as a result of the interactions of the two dominant air masses in Nigeria known as the Continental tropical(north easterlies) and the Maritime tropical (south westerlies) , begins in central Nigeria while the Monsoons from the south Atlantic ocean arrives in central Nigeria in July transporting with it high humidity, heavy cloud cover and heavy rainfall which can be daily occurrence lasting till September when the monsoons gradually begin retreating southward to the southern part of Nigeria. Rainfall amount in central Nigeria varies from 1,100 mm (43.3 in) in the lowlands of the river Niger Benue trough to approximately 2,000 mm (78.1 in) along the south western escarpment of the Jos Plateau.

The tropical dry climate or Sahel climate, is the predominant climate type in the northern part of Nigeria. Annual rainfall amount are lower compared to the southern and central part of Nigeria. The rainy season in the northern part of Nigeria last amount only three to four months (June–September). The rest of the year is hot and dry with temperatures climbing as high as 40 °C (104.5 °F) .

Alpine climate and highland climate or mountain climate are found on highlands states in Nigeria. Highlands with the alpine climate in Nigeria, are well over 1,530 metres (4,988 ft) above sea level. Due to their location in the tropics, this elevation is high enough to reach the temperate climate line in the tropics thereby giving the highlands, mountains and the plateau regions standing above this height, a cool mountain climate.

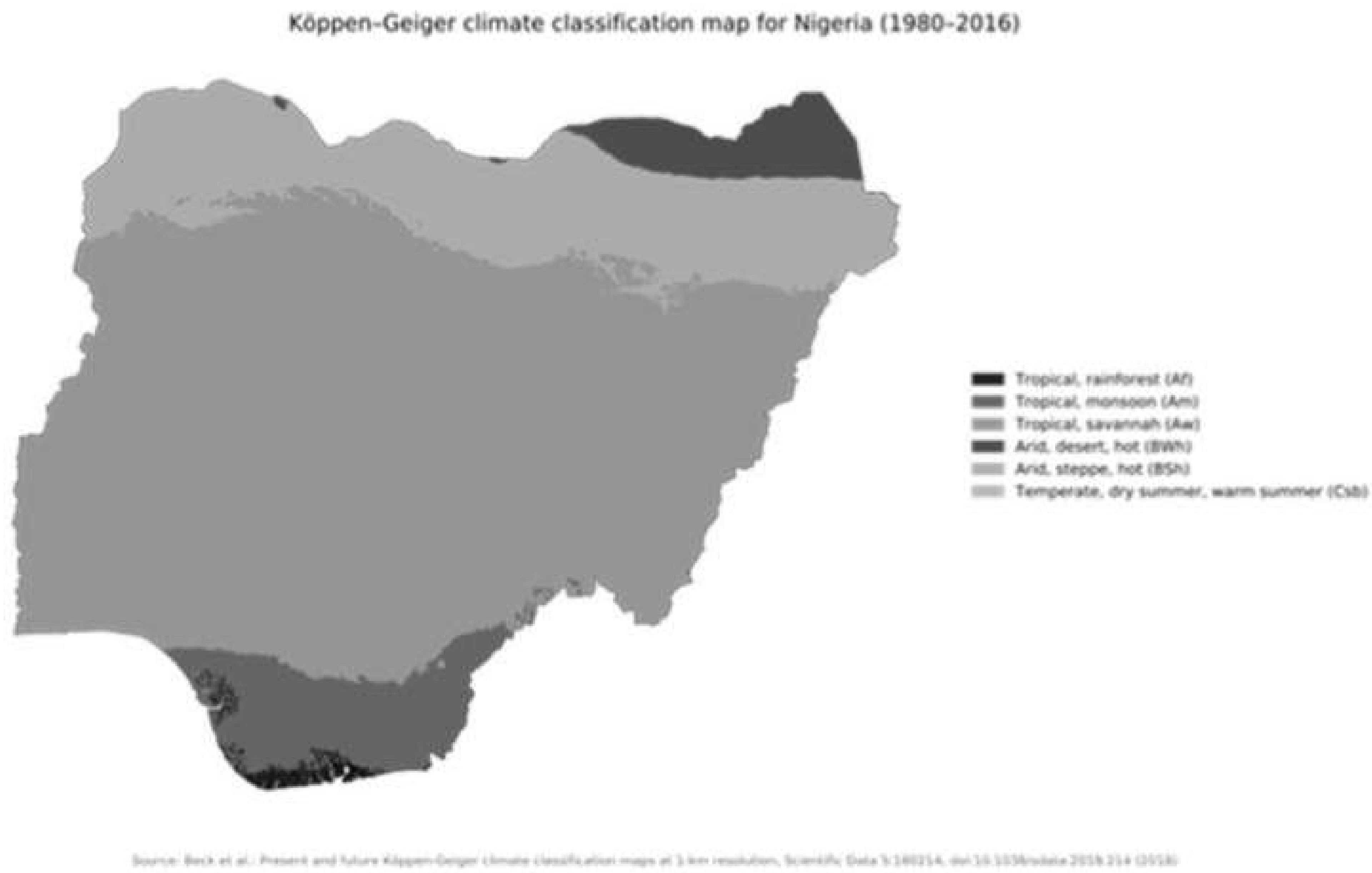


Fig. 1.2- Map of Nigeria with different climate conditions

Nigeria, like the rest of West Africa and other tropical lands countries, has only two seasons. These are the dry season and the rainy season. The dry season is complemented by a dusty laden air mass from the Sahara Desert, locally known as Harmattan, or by its core name, The Tropical Continental (CT) air mass, while the rainy season is heavily influenced by an air mass originating from the south Atlantic ocean, locally recognised as the south western wind, or by its main name, The Tropical Maritime air mass. These two major wind systems in Nigeria are known as the trade winds.[17]

1.2.1. Tropical maritime air mass

The tropical maritime air mass (MT) is accountable for Nigeria's rainy season. This wind (the tropical maritime air mass) invades the nataion from February in the southern part of Nigeria while it takes longer for the wind to fully cover the whole of the country, reaching the north part of Nigeria in June. Its invasion is as a result of the northward retreat, of the tropical continental air mass known as the harmattan. The northward retreat of the tropical continental air mass, is caused by the sun's northward swing from the tropic of capricorn in the southern hemisphere to the tropic of cancer in the northern hemisphere.

This move starts from early February and ends in mid June, when the sun is fully overhead, at the tropic of cancer in the northern hemisphere.[17]

Throughout this northward migration of the sun as a result of the earth tilting along its axis, the sun crosses the equator (around March), moving over West Africa at this time on its journey to the northern hemisphere. West Africa comes directly under the sun at this time. The sun is overhead during west Africa and over Nigeria during this period of the sun's northward migration to the tropic of cancer in the northern hemisphere.

The whole of West Africa is heated extremely as result of the increased insolation received from the sun being overhead over West Africa. Temperatures can rise as high as 36 °C (97.0 °F) over west Africa during this time. Temperatures in the north part of Nigeria can go as high as 49 °C (119.4 °F) in cities like Maiduguri.

The high temperatures coupled with a rise in insolation causes a region of low pressure to develop over West Africa and Nigeria (between March to May). The Tropical continental air mass from the Sahara Desert in the northern part of west Africa, is destabilized due to the overheating of the land surface in west Africa and Nigeria at this time. The Tropical continental air mass begins to retreat northwards to the Sahara Desert due to massive heating of the land which transfers heat in the form of convection into the Tropical continental air mass which organizes the main layer of air above the land. This transfer of heat in the Tropical continental air mass in turn, causes the wind to expand and become lighter as this is the normal behaviour for winds moving above intensely heated grounds. The Tropical continental air mass loses its strength as a major air mass in the region of west Africa and over Nigeria at this time (around February in the southern part of Nigeria to June in northern Nigeria) and initiates to retreat coupled with the rising of air in form of convection within this air mass Tropical continental air mass, further weakening the domination of the wind over west Africa and Nigeria. The Tropical continental air mass finally retreats from most share of Nigeria, and the West African atmosphere around April to May, leaving a bare atmosphere over Nigeria. The sun's rays move into the air of Nigeria more forcedly than it does during the presence of the Tropical continental air mass, which contained dust (in form of haze) that reduced the intensity of the sun. The overheating of the West Africa land mass and Nigeria in particular creates a low pressure region over West Africa and Nigeria. This low pressure zone attracts the Tropical Maritime Air mass (MT) from the South Atlantic Ocean since areas of low pressures experiences inward blowing winds because winds are moving air blowing outwards from regions of high pressure to regions of low pressure.

The Tropical Maritime Air mass is a warm humid and unstable trade wind due to its warmth. Convectional currents are easily set up within the air mass whenever there is little instability in the air mass as a result of a slight to a very high orographic uplift in mountainous regions like the obudu plateau or the heating of the land which can trigger the formation of cumulonimbus cloud leading to thunderstorms within the air mass.

During the dominance of the Tropical Maritime Air mass (MT) in the rainy season of Nigeria, mornings are bright and sunny, the sun's heating of the land in the mornings and afternoons sets up convectional currents, these currents rise vertically and cumulonimbus clouds are formed, by afternoons to evenings, torrential downpour follows. [16]

The African easterly waves or the Easterly wave is another main contributor of rainfall throughout the summer monsoons months of May till September in Nigeria.

The nature of this waves changes at around the 16 degrees line. The waves that pass south of this line carry moisture and generate convection that leads to rain clouds. Nigeria's northern end is south of the 16 degrees line at about 15 degrees. Nigeria's location in the wetter part of the easterly waves south of the 16 degree line creates wetter climatic conditions for Nigeria especially during the monsoons.

1.2.2. Tropical continental air mass

The Tropical Continental Air mass (CT) also known as the Harmattan, is a wind originating from Northern part of Africa which crosses the Sahara Desert into west Africa to Nigeria. This air mass controls Nigeria's climate during the dry season from December to March. The Tropical continental air mass is dusty and creates a haze within the atmosphere of West Africa and Nigeria when it predominates. The haze is as a result of the dust within the air mass preventing visibility and obstructing much of the sun's rays from reaching the earth. It is also a dry air mass formed over land in an area close to equator. An example of Tropical Continental is a warm air mass that forms over north Mexico.

1.3. Effects of the tropical continental air mass

The air mass has no ability of creating rain due to low humidity within the it, since it crosses the Sahara Desert, it picks up dust as an alternative of water thereby creating little chances for rainfall.

The air mass makes life difficult as a result of slightly low visibility which hampers transportation. The dust haze creates an almost desert conditions in the country during the dominance of the Tropical continental air mass (the harmattan). But it's arrival brings some relief to farmers since the low humidity present in the air quickens the drying of their farm crops.

1.3.1 Temperature

Temperatures in Nigeria vary according to the seasons of the year as with other lands found in the tropics. Nigeria's location in the tropics has given her a tropical hot climate. Nigeria's seasons are determined by rainfall with rainy season and dry season being the main seasons in Nigeria.

The rainy season of Nigeria carries in cooler weather to the country as a result of an increased cloud cover that acts as an obstruction of the intense sunshine of the tropics by blocking much of the suns rays in the rainy season; this in turn cools the surrounding, and the winds above the ground remains cool thereby making for cooler temperatures during the rainy period. But afternoons in the rainy season can be hot with high humidity, a feature of tropical climates. In the rainy season it is damp, and the rainfalls are usually surplus.

The dry season of Nigeria is a period of little cloud cover in the southern part of Nigeria to virtually no cloud cover in the north part of Nigeria. The sun shines through the atmosphere with little obstructions from the clear skies creating the dry season in Nigeria a period of warm weather conditions. In the middle of the dry season in December, a dusty wind from the Sahara Desert termed the Harmattan enters Nigeria from the north-eastern part of the country hindering sun rays partially from shining and also creating haze in the atmosphere, this activities of the wind reduces temperatures considerably saving inhabitants for a period of time, from the scorching temperature that would have happened as a result of clearer skies throughout the dry season. But with the withdrawal of this wind around March to April following the onset of the rainy season, temperatures can go as high as 46 °C (114.2 °F) in some states of Nigeria.

Semi temperate weather conditions prevail on the plateaus in central Nigeria beyond 1,220 metres (3,967 ft) above sea level, namely the Jos Plateau. Temperatures on the Jos plateau ranges between 17 °C to 26 °C which are cool during the year.

Temperate weather conditions happen on the highlands beside the Nigeria Cameroon boundary, in the eastern part of Nigeria. Highlands in this region get an average height of more than 1,574 m (5,000 ft) to some standing above 2,200 metres (6,962 ft) above sea level. The climate on these highlands is temperate all year. The major highlands in this region are the Obudu Plateau above 1,684 m (5,197 ft), Mambilla Plateau above 1,584 m (5,000 ft) and Mt. Chappal Waddi exceeding 2,000 m (6,562 ft).

1.3.2. Topography

Nigeria's most expansive topographical region is that of the valleys of the Benue River and the Niger valleys (which merge into one another and form a "y" shaped confluence at Lokoja). Plains rise to the northern of the valleys. To the southwest of the Niger there is "rugged" highland, and to the southeast of the Benue hills and mountains are found all the way to the territory with Cameroon. Coastal plains are found in both the southeast and the southwest.

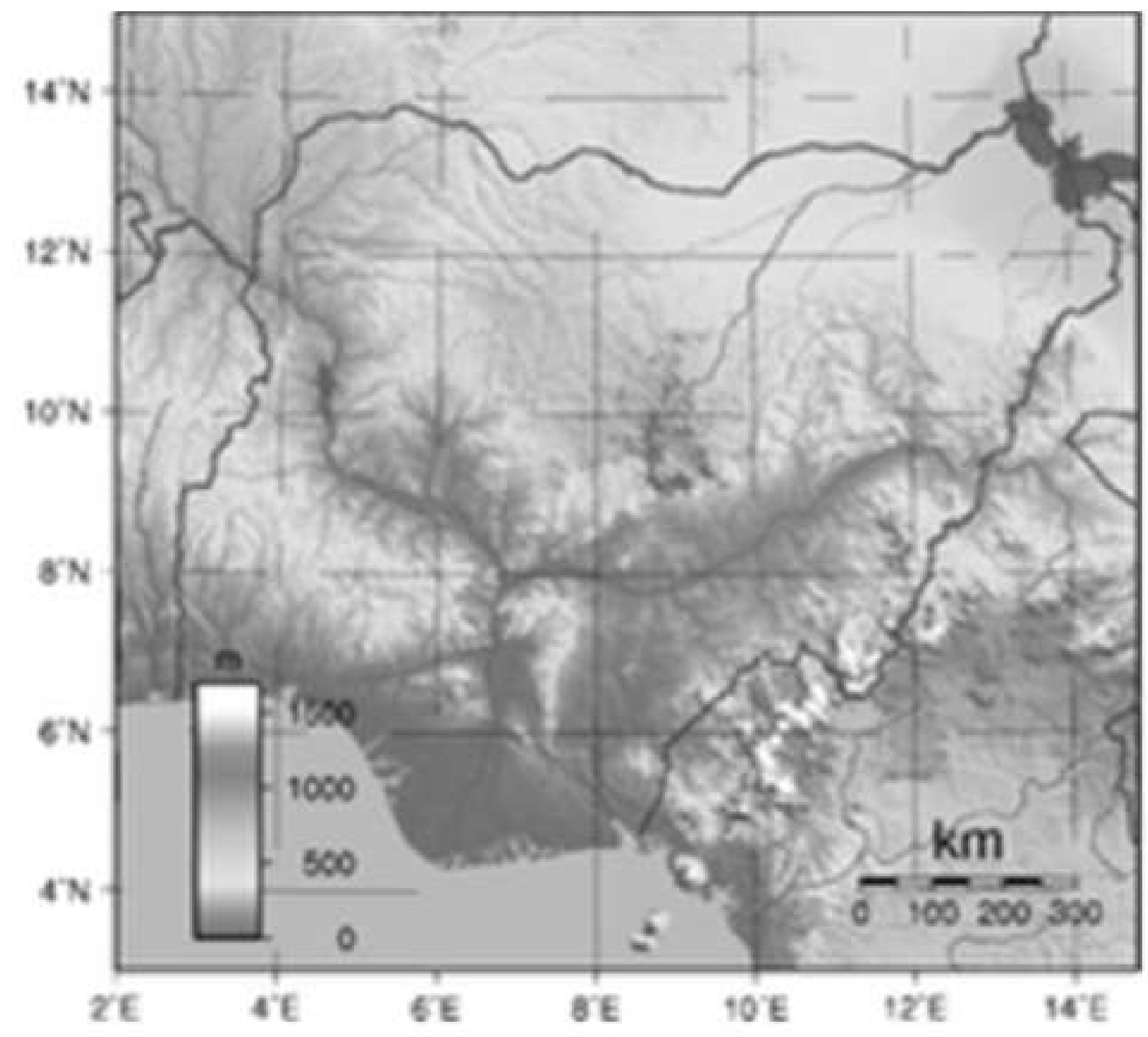


Fig. 1.4- Topography of Nigeria

The Niger Delta is situated in the southern part of Nigeria. It is one of the world's major arcuate fan-shaped river deltas.

The riverine area of the Niger Delta is a coastal belt of swamps neighbouring the Atlantic Ocean. The swamps are vegetated tidal flats made by a reticulate pattern of interconnected meandering creeks and tributaries of the Niger River.[16]

1.3.3. Niger Delta Vegetation

The vegetation of the Niger Delta involves mainly of forest swamps. The forest is of two types, nearest the sea is a belt of saline/brackish Mangrove swamp separated from the sea by sand beach ridges within the mangrove swamp. Numerous sandy islands occur with fresh water vegetation. Fresh water swamps gradually supersede the mangrove on the landward side. About 75% of Nigeria's crude oil and gas production is found there.

1.3.4. The Rainfall in Niger Delta

Rainfall in the coastal belt of the Niger Delta is pretty heavy due to the closeness of the Delta region to the equator. Yearly rainfall totals vary from 2,500 to over 4,000 mm.

Niger Delta cities and their yearly rainfall totals in millimeters:

- Warri — 2,830 mm
- Forcados (coastal town in the Niger Delta) — 4,870 mm
- Port Harcourt — 2,500 mm
- Calabar — 3,170 mm (rainiest city with over one million people in Nigeria)
- Bonny (south of Port Harcourt) — 4,200 mm

1.3.5. Climate

Nigeria has a tropical climate with flexible rainy and dry seasons, depending on region. It is hot and wet most of the year in the southeast, but dry in the southwest and beyond inland. A savanna climate, with marked wet and dry seasons, prevails in the northern and western, while a steppe climate with petite precipitation is found in the far north.

In general, the duration of the rainy season declines from south to north. In the south the rainy season continues from March to November, while in the far north it lasts only from mid-May to September. A marked interruption in the rains take place during August in the south, resulting in a short dry season frequently referred to as the "August break." Precipitation is heavier in the south, particularly in the southeast, which receives more than 130 inches (3,000 millimetres) of rain a year, compared with about 60 inches (1,700 millimetres) in the southwest. Rainfall falls progressively away from the coast; the far north receives no more than 30 inches (600 mm) per annum.

Temperature and humidity stay relatively constant during the year in the south, while the seasons vary considerably in the north; during the northern dry season the daily temperature range becomes abundant as well. On the coast the mean monthly maximum temperatures are steady during the year, remaining about 92 °F (31 °C) at Lagos and about 92 °F (34 °C) at Port Harcourt; the mean monthly lowest temperatures are approximately 73 °F (22 °C) for Lagos and 69 °F (20 °C) for Port Harcourt. In general, mean maximum temperatures are higher in the north, whereas mean minimum temperatures are lower. In the north-eastern city of Maiduguri, for example, the mean monthly maximum temperature may go beyond 101 °F (39 °C) during the hot months of April and May, however in the same season frosts may occur at night. The humidity normally is high in the north, nonetheless it falls during the *harmattan* (the hot, dry northeast trade wind), which blows for more than three months in the north but rarely for more than three weeks along the coast.

Average weather, temperature, rainfall

- **The coast** - Lagos
- **North** - Kano
- **The center** - Abuja, Jos

In Nigeria, the climate is tropical, semi-arid in the north, and progressively raining as you move southward. In detail, there is a rainy season due to the African monsoon, which is increasingly longer and more intense from south to north. In the north (see Sokoto, Kano, Maiduguri), the rainy season lasts only four months, from June to September; in the center (see Abuja), it occurs from April to October; whereas in the south (see Lagos, Benin City, Port Harcourt), it occurs from March to October; and finally, in the south-east, which is the wettest area (see Calabar), it goes from March to November. Annually **precipitation** is under 500 millimeters (20 inches) in the end north-east, on the shores of Lake Chad, it ranges bewteen 1,000 to 1,500 mm (40 to 60 in) in the central region, it go above 2,000 mm (80 in) in the south, and it even go beyond 3,000 mm (120 in) in the far south-east (the map below indications the average rainfall, in millimeters on the left and in inches on the right). It states that the vegetation varies considerably, in fact, in the north, we find the semi-arid Sahelian landscape, the savannah in the center, the mangroves in the Niger Delta and the coastal areas and the forests in the south. In the north, but specifically in the far north-east, in the area of Lake Chad, where the rains are not very heavy even in summer, there is an interchange of rainy and sunny periods, during which the heat returns to be extreme, even in the rainy season.[17]

The temperatures also differ in a remarkable way subject on the climatic zones. In the north, winter is warm and dry; it can get uncomfortably very hot during the day, up to 42

°C (104 °F), but it's generally cool at night, and it can even get cold in the northern hilly regions, where cold records are around freezing (0 °C or 32 °F). By February, the heat rises in all the inland areas, and it becomes scorching in the center-north from March to May, when temperatures can easily reach 41 °C (105 °F). On the contrary, in the south, the rise in temperature is limited, both because of the proximity to the ocean and because the rain showers start earlier. The existing hot and dry air mass, small tornadoes may form. From June to September, the air is humid and the sky is commonly cloudy throughout the nation; temperatures are uniform, and are everywhere around 29/32 °C (83/89 °F); the daytime temperatures are lesser than in winter, but relative humidity is always higher.

Fig. 1.5- Map of Nigeria showing average wind speed

1.3.6. The North

In the north, winter nights are always cool, and sometimes even cold. From March to May, the temperatures rise rapidly, and the heat becomes scorching; in summer, when the monsoon arrives, the temperature falls, but at the same time, the humidity rises.

- **Kano**

Here is the average temperatures of Kano, situated at 500 meters (1,700 feet) above sea level, in the north. Show in table 1.1.

Table 1.1.

Kano - Average temperatures												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min. (°C)	13	14	19	22	23	22	21	20	21	19	15	123
Max. (°C)	31	33	37	39	36	34	31	30	31	34	34	31
Min. (°F)	54	57	64	71	73	72	70	68	70	66	59	54
Max. (°F)	86	91	99	101	100	93	88	84	89	93	93	87

In Kano, precipitation doesn't reach 900 millimeter (35.5 in) per annual. Here is the average precipitation in table 1.2

Table 1.2.

Kano - Average precipitation													
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Prec.(mm)	0	0	2	10	71	114	205	310	142	13	0	0	864
Prec.(in.)	0	0	0.1	0.4	2.7	4.5	8.1	12.2	5.5	0.5	0	0	34.1
Days	0	0	0	1	6	7	12	17	10	2	0	0	53

In Kano, the sun shines all year round, but in summer, the sunshine hours decline a little because of the monsoon. July and August, in addition to being the dampest months, are also the least sunny.[16] Here is the average sunshine in table 1.3

Table 1.3.

Kano - Sunshine												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Hours	8	8	8	8	8	9	7	7	8	9	9	8

1.3.7. THE CENTER

In the centre, winter is hot, with high temperature around 34/36 °C (92/96 °F) in December and January. In this period, the *Harmattan* frequently blows, a wind able to bring dust from the desert and to reduce visibility. But then, the monsoon arrives earlier, so much so that the temperature starts to reduce already during the month of April.

- **Abuja**

Here are the average temperatures in Abuja, the capital, situated in the centre of the country, at 500 meters (1,600 feet) above sea level. Here is the average temperature in table 1.4

Table 1.4

Abuja - Average temperatures												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min (°C)	21	25	25	26	20	18	22	18	19	21	16	16
Max (°C)	35	37	37	35	33	31	29	29	30	33	35	36

Min (°F)	69	79	75	77	68	64	72	64	64	72	62	61
Max (°F)	94	100	99	97	91	88	84	84	86	90	95	94

In Abuja, rainfall sums to 1,200 mm (47 in) yearly, including more than 120 mm (4.2 in) per month from May to October. Here is the average rainfall and the average precipitation in table 1.5

Table 1.5.

Abuja - Average precipitation													
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Prec.(mm)	2	5	10	65	135	165	220	265	255	105	5	1	1220
Prec.(in)	0.1	0.2	0.4	2.6	5.3	6.5	8.7	10.4	10	4.1	0.2	0	48
Days	0	0	1	4	9	12	14	16	16	8	0	0	82

Jos

In the **Jos Plateau**, in the centre of the country, the temperature is fairly mild: in Jos, the capital of the Plateau State, situated at 1,300 meters (4,000 feet), daytime temperatures range from 29 °C (83 °F) in January to 31/33 °C (88/91 °F) in March and April, whereas they fall to around 24/26 °C (75/78 °F) in July and August. Here is the average temperature in table 1.6

Table 1.6

Jos - Average temperatures												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**

Min (°C)	14	16	18	19	18	18	17	17	17	17	16	14
Max (°C)	28	30	32	31	29	27	25	24	27	29	29	28
Min (°F)	57	61	64	66	64	64	63	63	63	63	61	57
Max (°F)	82	86	90	88	84	81	77	75	81	84	84	82

1.3.8. THE COAST

In the south, in cities located in the coastal area (Lagos, Benin City, Port Harcourt, Calabar), winter is hot, with highs around 30/32 °C (86/90 °F), but it's also more humid, though tempered by afternoon breezes; here, cloudy skies are frequent, at least in the morning, while in the north and center, as mentioned, the winter is sunny. Sometimes, however, the Harmattan can arrive also on the coast. In this area, the temperature in spring does not increase almost at all, both because of the presence of the sea and because the rains begin early.

- **Lagos**

In **Lagos**, a large metropolis, where the urban heat island effect is noticeable, in addition to moisture coming from the sea and the lagoon, the heat is particularly unpleasant, but at least, being on the coast, it receives the breeze from the sea as well. Here are the average temperatures of Lagos in table 1.7

Table 1.7

Lagos - Average temperatures												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**

Min (°C)	22	24	24	24	23	23	22	22	22	22	23	22
Max (°C)	32	33	33	32	31	29	28	28	29	30	31	32
Min (°F)	72	75	75	75	73	73	72	72	72	72	73	72
Max (°F)	90	91	91	90	88	84	82	82	84	86	88	90

In the western part of the coast, between mid-July and late August, the rains diminish a bit: in Lagos, June is the wettest month with 310 mm (12 in), then the rainfall decreases to 255 mm (10 in) in July and to 110 mm (4.3 in) in August, but the sky remains cloudy and moisture high. Here is the average precipitation in Lagos in table 1.8.

Table 1.8

Lagos - Average precipitation													
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Prec.(mm)	15	40	75	140	205	310	255	110	165	135	55	20	1540
Prec.(in)	0.6	1.6	3	5.5	8.1	12.2	10	4.3	6.5	5.3	2.2	0.8	60.6
Days	2	3	6	9	12	16	13	12	13	11	5	1	103

In Lagos, and in general in the south of Nigeria, the sun does not shine very often, even in the dry period, while in the rainy season, the sky is often cloudy.

Lagos - Sunshine												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Hours	5	6	6	6	6	4	3	4	4	5	6	6

The **ocean** in Nigeria is adequately warm to swim in all year round, although care should be taken with regard to the tides. However, as mentioned, the sun does not shine very frequently on the coast, even in the dry months. Here is the average sea temperatures near Lagos in table 1.9

Table 1.9

Lagos - Sea temperature												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp (°C)	29	29	29	30	29	28	26	25	26	28	30	29
Temp (°F)	83	82	84	83	85	82	78	79	79	81	84	82

In the south, the rainiest region, the decline in rainfall in early July and August doesn't occur: in **Calabar**, where 3,000 mm (120 in) of rain fall per year, rainfall remains around 450 mm (16 in) every month from June to September. In the south-east of Nigeria, the Cross River National Park is a alpine area, misty and covered with forests.

1.4. Conclusion

2. Execute analyse of gas and oil industry in Nigeria which have important influence on Nigeria's economy.
3. The Nigeria is a big country with different climatic and geographic conditions which influence the reliability of work of different equipment.

PART 2

INFLUENCES OF DIFFERENT CLIMATIC CONDITIONS AT COMPRESSOR STATIONS WORKING PLANT IN NIGERIA

2.1. Brief information about Natural Gas and Oil Compressor Stations

Compressor stations are central part of the natural gas pipeline network that moves natural gas from individual producing well sites to final users. As natural oil and gas moves through a pipeline, friction, distance, and elevation differences slow the motion of the gas, and decrease pressure. Compressor stations are positioned strategically within the gathering and transport pipeline network to maintain the pressure and flow of gas to final consumer.

While the equipment used at a natural gas compressor station can vary slightly, a compressor station typically consists of a building housing the compressors unit(s), some yard piping, coolers, a gas or electric power source, and safety systems. Some station yards may include small storage tanks and odorization aggregates. The major operating equipment at a compressor station is enclosed in security fencing to allow for safe, controlled access only by natural gas compressor station authorized personnel. Depending on the compression capacity installed, a compressor station typically occupies approximately five (4) to thirty (32) acres of land. When additional land is available, a compressor station may be placed on larger parcels, often 20 to 43 acres, with some greater than 100-150 acres. 4 Interstate natural gas companies use these larger parcels, as well as landscaping and other visual design considerations, to provide additional visual or space buffer from the local community and to reduce noise, visual, and air impacts to neighbors. Typical interstate natural gas transmission compressor stations do not dehydrate natural gas received into the facility. In this sector of the natural gas industry, most dehydration equipment is located at natural gas storage facilities (which may operate compressors on-site or have nearby compression). Natural gas storage facilities contribute to the reliability of pipeline-quality natural. [5]

2.1.2. Compressor Station Components

Natural gas and oil enter a compressor station through station yard piping and is passed through scrubbers and filters to remove any liquids and take out solids or other particulate matter that might be in the gas stream (Figure 1). Once the natural oil and gas stream has been washed, it is directed through additional yard piping to different compressors. Computers regulate the movement and number of units that are needed to handle the planned system flow requirements. Most gas and oil compressor units operate in parallel, with individual compressor units providing the needed supplementary pressure before directing the gas back into the pipeline with full operational pressure restored. Once the required boost in pressure is very high, several compressor units can be operated in stages (serially) to achieve the desired pressure in stages.[5]

As natural gas or oil is compressed, heat is generated and must be dissipated to cool the gas stream before leaving the compressor facility. For every 100 psi rise in pressure, the temperature of the gas stream rises by 7-8 degrees. Most compressor stations have an aerial cooler system to dissolve excess heat (an "after" cooler). The heat produced by the operation of each compressor units is dissipated via a sealed coolant system similar to an locomotive radiator.

Most compressor stations are fuelled by a portion of the natural gas moving through the station, although in more or less areas of the country, all or some of the units could be electrically powered primarily for security or environmental reasons. Gas-powered compressors could be driven by conventional piston engines or natural gas turbine units. There are site design and operational transformations, as well as unique air and sound creations, between these competing compressor engine technologies.

There could be one or more individual compressor units at a compressor station, which can be out in the open air, or more often, housed in a building to facilitate maintenance and sound management. Newer units are mostly housed one per house, but there might be multiple units in one large building. Compressor houses commonly incorporate insulated walls, protected exhaust systems, and advanced fan apparatus to dampen sound. modern constructed compressor structures may incorporate these features where local, province, or federal regulations require noise moderation.

Figure 2.1- Inside compressor building.

2.2. Ambient Temperature Effect on Pipelines and Compressor Stations

The performance features of land-based gas turbines are identified to be significantly affected by the operating conditions and ambient including unavoidable machine deterioration. This research makes a collection of gas turbines for use as compressor station drivers on two natural oil and gas pipelines in Nigeria taking into details the local site conditions of ambient temperature and height as well as some level of turbine weakening. The analysis involved modelling and simulating the onsite performance of five gas turbine engines in the power requirement range of the compressor stations as verbalized by pipeline gas flow research. The total effect of all considered elements was an engine thermal efficiency loss of 5.5% and a 27.3% decrement in power outputs. Designated turbines for driving the compressor stations should therefore have a minimum of 27.3% more power productivity than the value recognized by pipeline flow analyse. More largely, the results suggest that gas and oil pipelines of 24-inches diameter with a through put of 450 MMSCFD require a compression power of approximately 0.04 MW/km if flow pressure is to be maintained at least of 50 bar. Also, a gas turbine driver should be capable of 0.05 MW/km of pipeline known the local site conditions and engine deterioration.[14]

2.2.1 Environmental Parameters Influence compressor station aggregates Centrifugal Performance

The performance of a dynamic compressor is actual much dependent on environmental or ambient conditions. The impact of the diverse environmental parameters and their effect on aggregates performance are detailed below.[14]

The environmental parameter that influences the performance are:

1. Relative humidity
2. Inlet temperature
3. Cooling water temperature
4. Inlet pressure

2.2.2. Inlet Temperature

The inlet temperature of the air has huge effect on the density of the air at the entrance of the compressor and will have influence on the kinetic energy transferred by the vanes and blades to the air. An increased density at lower intake temperatures will cause a higher free air delivery (acfm) and also higher power consumption of the compressor.

Another result of the alteration in air or gas density is the available turndown of the compressor. That is the flow array where efficient regulation through use of a throttle valve or inlet guide vanes is possible. From the graphics below, it is clear that with lower temperatures, *a* higher turndown variety is available.[14]

Figures 1 and 2 shows the special effects of inlet temperature on the working performance of a turbo compressor.

Alterations in inlet temperature produce huge changes in working performance. In cold weather, a centrifugal compressor can deliver slightly more weight flow of air than in warm climate — if the drive is sized to deliver the additional power required.

Lower inlet temperature:

- Rises the maximum capacity (weight flow) at a given discharge pressure.
- Rises the surge pressure.
- Rises the power consumption (horsepower).

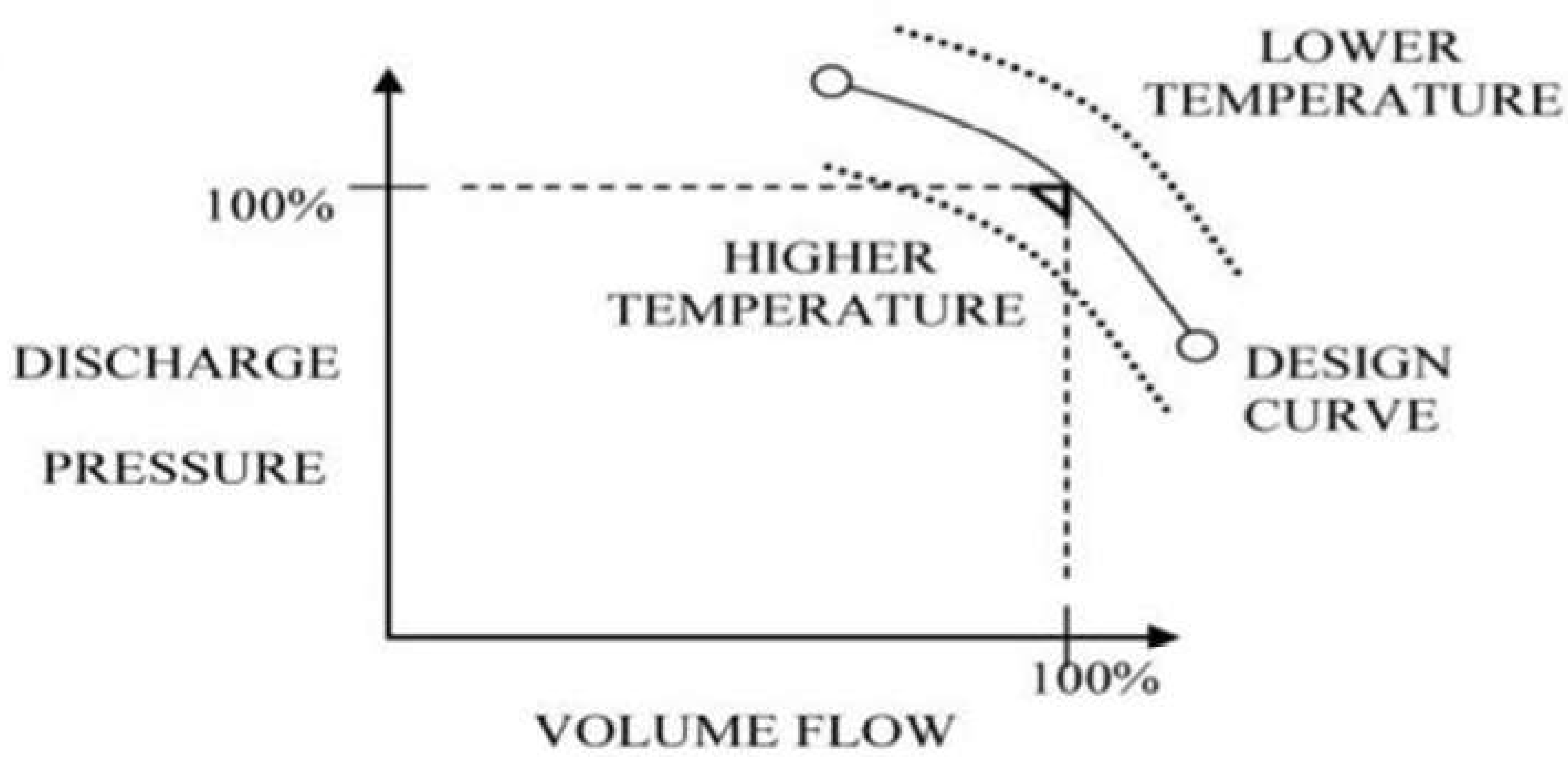


Figure 2.2- Density of air rises with decreases of air temperature.

Higher inlet temperature:

- Decreases the power consumption (horsepower).
- reduces the surge pressure.
- reduces the maximum capacity (weight flow) at a given discharge pressure.

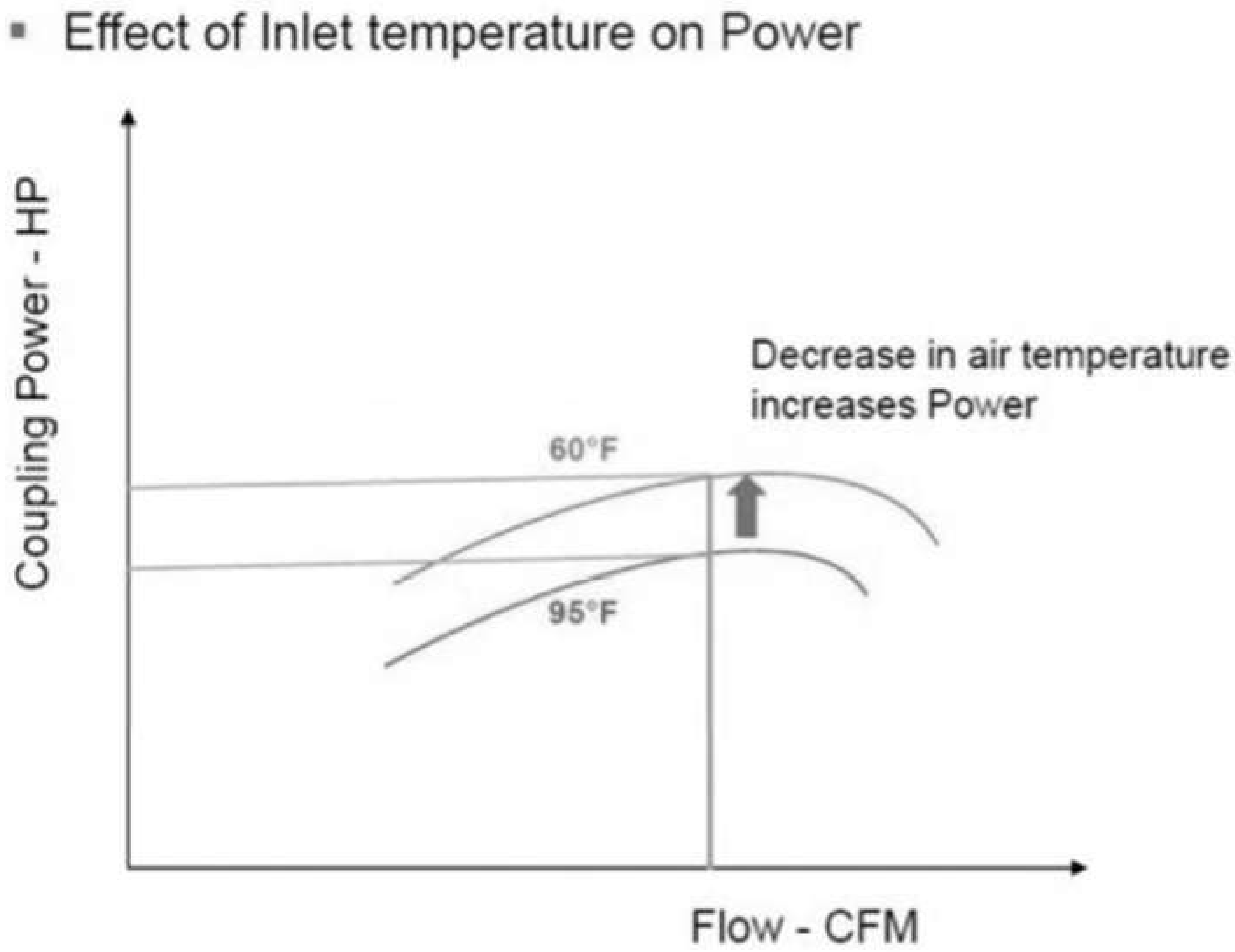


Figure 2.3- Influence of inlet temperature on power

The aforementioned parameters have similar effects onworking compressor performance. The impact of these parameters and results can also be understood from the performance graphs used above.

2.2.3. Inlet Pressure

A decline in inlet pressure will decrease the density of the air at the compressor intake. As with greater temperatures, it will result in low free air distribution and power. Changes in inlet pressure could be caused by spoiled inlet filters or changing barometric pressure. The same thing goes for the accessible turndown — low intake pressure will result in lesser reachable turndown (See Figure 2.4). [14]

Low inlet pressure:

- Reduces the discharge pressure beside the entire curve.
- Reduces the maximum capacity (weight flow).

- Reduces power consumption or horsepower.

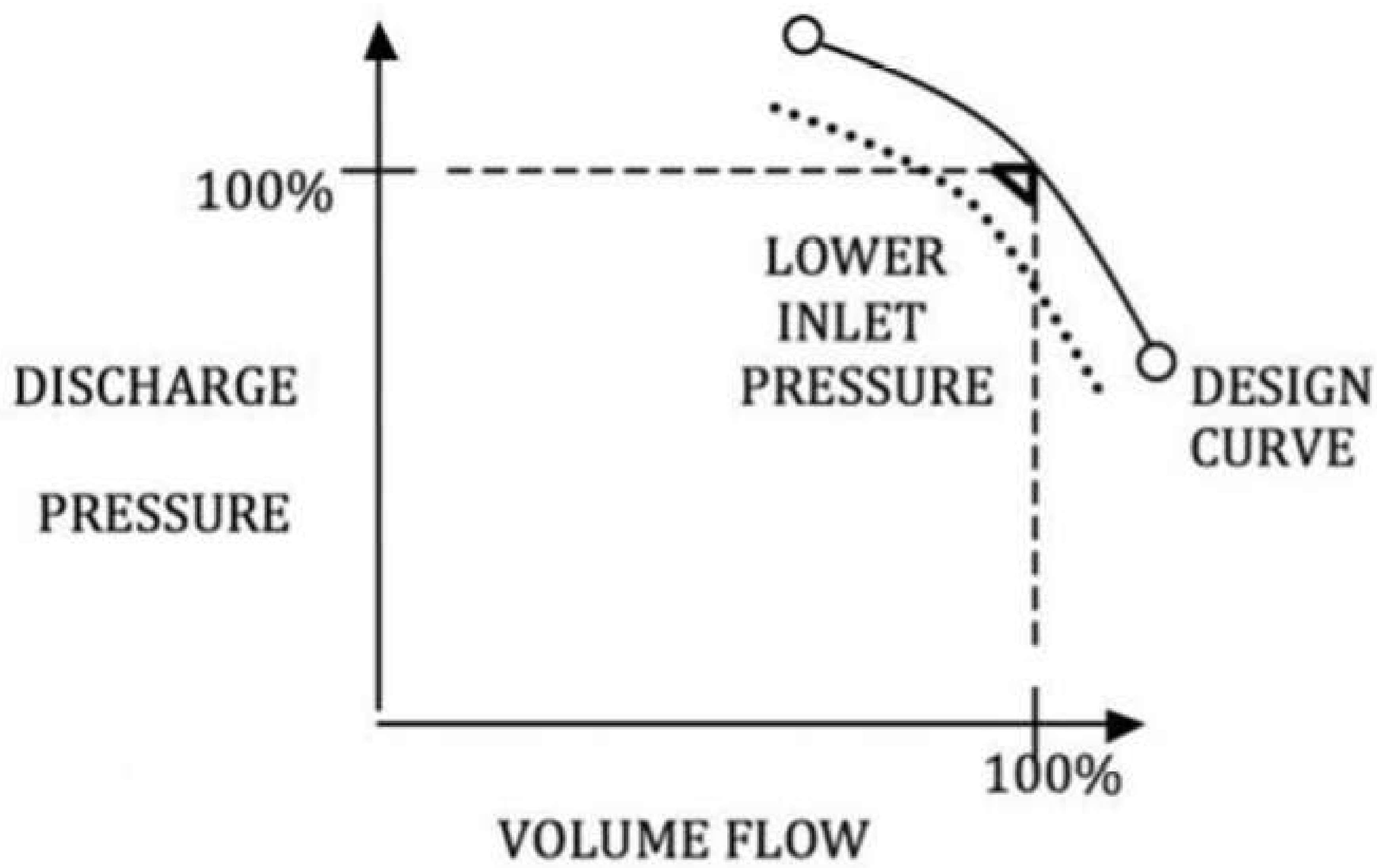


Fig. 2.4- Influence of inlet pressure effects on centrifugal compressor performance

2.3. Ambient Dustiness effect on compressor station aggregates

Dust Prevailing strong winds in August and September pick up and carry substantial amounts of fine dusts from beaches, lake shores, and streambeds. Wind-driven particles have an abrasive effect upon plants with tender growth. In addition to smothering, Large amounts of particles and materials borrow from many sites will be used to construct facilities and for selective backfill material. Excavation and transportation of materials will provide new sources which will add to the environment. The impact of dust from the pipeline construction activities is likely to be local. In addition to wind-carried dust, dust from operation of fixed-wing aircraft and helicopters from sand and gravel airfields and pads will produce unknown but long-term secondary impacts on vegetation to the downwind side of dust sources. Borrow areas will be required for long-term maintenance of the project. Long-term, incremental but unknown amounts of dust would be added to the environment from these sites. It is expected that some existing oil pipeline haul road would be used for carriage of construction materials.

Dust to the atmosphere by vehicles using the gravel road would be incremental and local might be created, but it is thought likely to be of slight consequence. Addition of There is no basis on which to estimate how much dust Release of Natural Gas Data supplied to the Nigerian Government (CAGPL, 1974) indicate routine maintenance procedures at compressor stations will result in the release of some natural gas. Compression turbines will expel approximately 150 Mcf (thousand cubic feet) of unburned natural gas. Block valves, pipeline failure or emergency shutdown would result in discharge of up to approximately 3,750 Mcf of natural gas into the atmosphere. During station startup, the main gas and propane Assuming that there are 15 miles between automatic. The natural gas will be odorless. Impact of the Environmental Noise from Construction Equipment. Existing levels of environmental noise in this area are not known but because of the preponderance of motorized equipment such as diesel drilling platforms, noise is pronounced locally. They move through an area (aircraft) or are placed in another location after a period of several days months (drilling rigs). Most noises are transitory. [3]

Environment effect compressor station Emissions of criteria pollutants produced during construction of the Trans-Saharan gas pipeline Pipeline Project and during operation of Compressor Station. Construction of the pipeline, both on and offshore, and its proposed facilities would cause temporary reduction of local ambient air quality due to emissions generated by construction equipment and fugitive dust. Primary emissions during construction activities would be respirable particulate matter in the form of dust generated by mechanical disturbance of soil Emissions would occur during equipment movement and site preparation activities. Since construction does not occur at a single location for any significant length of time, the impact of these emissions at any single location would be minor and short-term. Trans-Saharan gas pipeline would implement mitigation measures, such as watering construction areas, to control fugitive dust emissions. On cultivated land, the generation of dust by construction equipment would be comparable to that generated by farm equipment Shrubs, trees, and. grasses from the right-of-way must be cleared during construction and some emissions may result from the open burning of this debris Open bumping of land-clearing, but no permits are required Offshore the equipment emissions would be transient due to weather conditions and extremely variable in intensity The emissions from construction vehicles and equipment should have an insignificant impact on the air quality of the region, provided that construction equipment is properly maintained Criteria emissions produced during the operation of the compressor station would be combustion products from the combustion of natural gas, primarily NO and carbon monoxide (CO) produced by the turbines Trans-Saharan gas pipeline would install four new gas turbine-powered pipeline compressors at the proposed Compressor Station 100 Trans-Saharan gas pipeline would install the GE LM2500 + or similar model turbine, and the air quality impact is analysed based on four of these gas-powered turbines. All four turbines would be equipped with low-NO, bumper technology to reduce NO. Impacts from the combustion emissions. [3]

2.4. Ambient moisture effect on technical state of equipment

2.4.1. Relative Humidity (RH)

A rise in relative humidity decreases flow and power, and a reduction in relative humidity will increase flow and power. The adding of water vapour to the air makes air humid and diminishes the density of the air. This is due to the molar mass of H2O being less than that of air (See Figure 2.5). [5]

Higher relative humidity:

- Reduces the discharge pressure at surge.
- Reduces the maximum flow capacity (weight flow).
- Reduces the flow at which surge occurs.
- Reduces power intake (horsepower).

The greater condensate losses on high humidity days result in reduced flow transported to the plant air system.

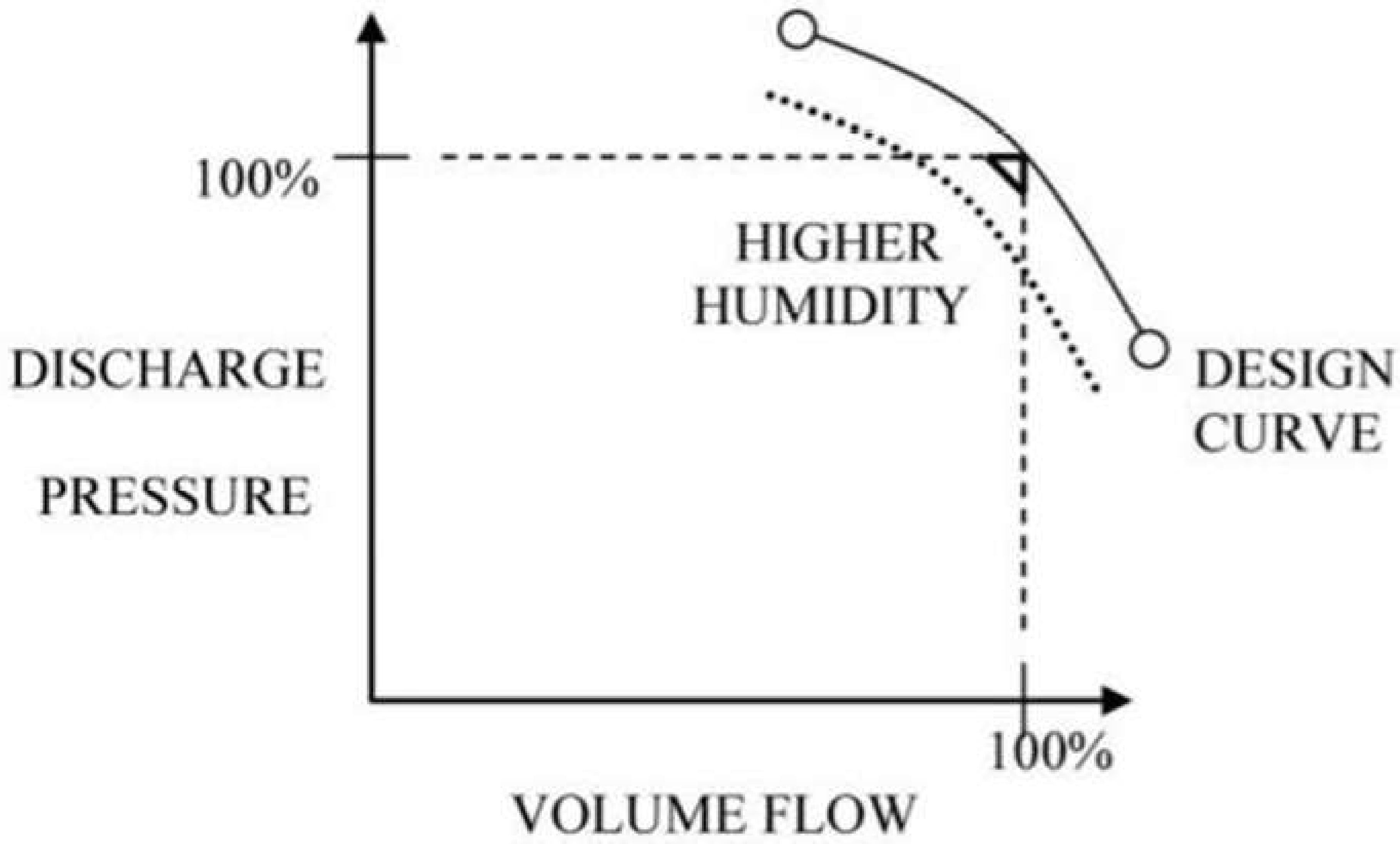


Fig 2.5- relative humidity Influence on centrifugal compressor performance

2.4.3. Water Temperature Cooling

The cooling water temperatures will have high effect on temperatures intake from the second stage and any additional stages — if presented. Cold water increases flow and power, and warm water reduces flow and power.

Another significant point to consider is motor sizing. If the motor/driver is designated based on performance at lesser inlet temperatures, it will guarantee that even during low inlet temperatures, the motor has sufficient power accessible to take care of flow rises. The consumer can take advantage of increased flow available from it compressor (See Fig. 2.6).

Cooling water temperature will have effect on the performance of the compressor stage after the initial stage. The affect in performance is related to that of inlet air temperature. This, of course, is real since cooling water temperature variations will openly affect the temperature of the air going through the second, third and subsequent stages, where there are intercoolers located among stages. [5]

Lesser cooling temperature:

- Rises discharge pressure.
- Rises maximum capacity of weight flow.
- Rises in power consumption of horsepower.

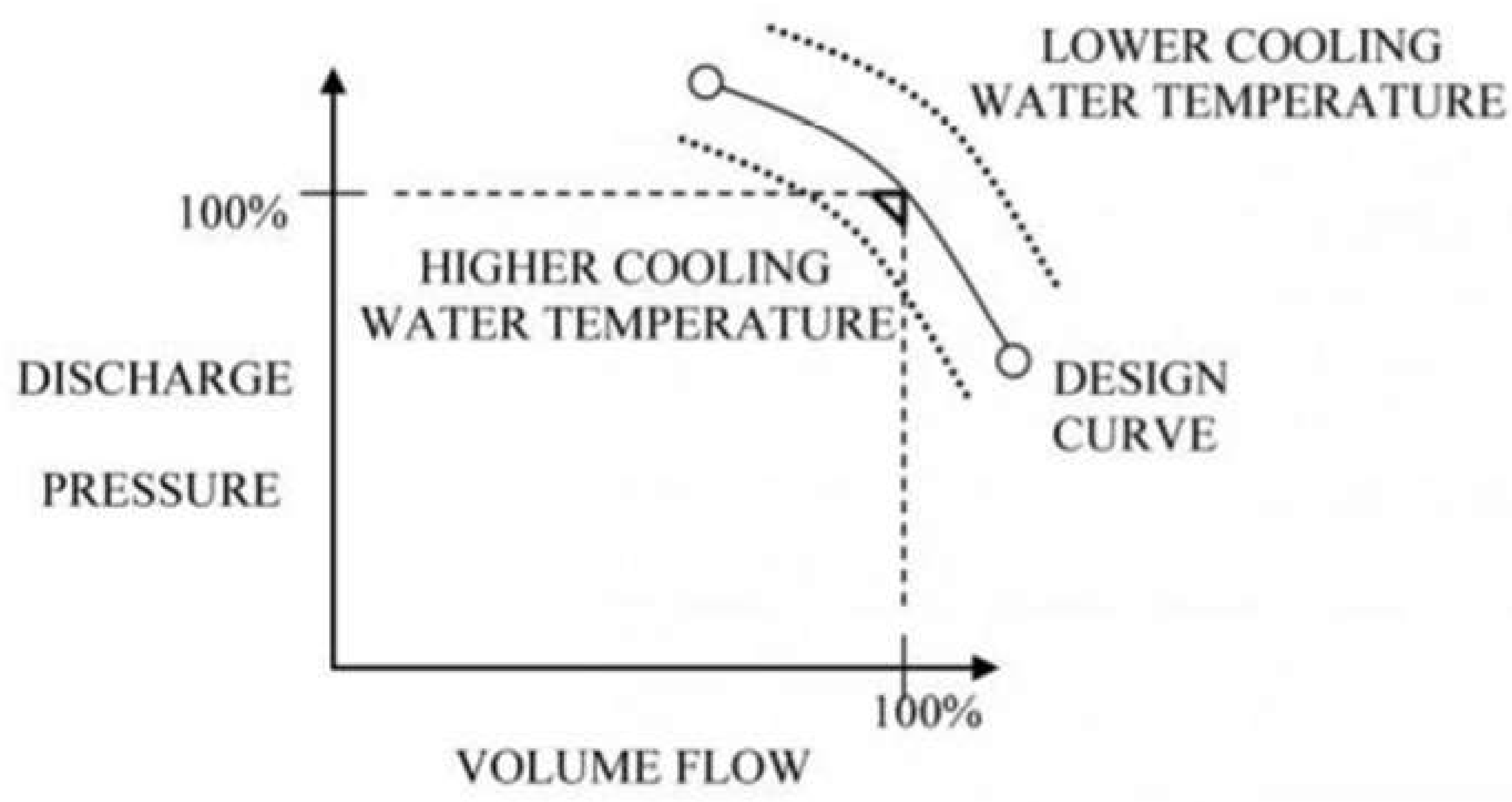


Fig. 2.6- The influence of water temperature cooling on centrifugal performance

Higher water temperature cooling:

- Reduces discharge pressure.
- Reduces maximum capacity of weight flow.
- Reduces power consumption of horsepower.

2.5. Influence of temperature distribution around pipelines for transport of natural gas on surroundings

The influence of different approaches for modelling heat transfer between a pipeline and the ambient was examined. The differences in exit temperatures between a steady and an unsteady heat transfer model are counted, as well as the effects of simulating the yearly oceanic temperature cycle over several years. A periodic difference between measured and modelled outlet temperature was established. The results show that the nonappearance of the heat storage period in the heat transfer model might only be a minor contributing factor to this difference. Presumptuous of error is caused by inexactness in the ambient temperature, the effect on the capacity is found to be the range of 0.13 and 0.5 %. [5]

Precise modelling of heat transfer starting from the pipeline to the ambient will influence all parts of pipeline simulation; from capacity valuation and inventory to modelled exit temperatures. Accurate simulations depends on precise measurements of fluid components and on the pipeline flow model. Furthermore, one requires dependable ambient temperature information and an exact heat transfer model of the pipelines to the ambient. Specific attention on the time-dependent explanation of the ambient temperature. For subsea pipelines could be delivered by an oceanographic model. The heat transfer between ambient and pipeline is strongly dependent on how the pipeline is positioned on the seabed. The burial depth of the pipeline, as well as the exclusion or inclusion of the ground heat storage duration in the heat transfer model have a significant role. For flow control purposes, typically a steady heat transfer report is chosen. Heat transfer models that include the heat storage term usually depend on a one-dimensional radial illustration of the pipe wall and soil.

To decrease capacity underestimation, the average roughness is based only on steady-state phases with relatively high flow rates.

Measurements of water temperatures at the sea level are scarce.

For this motive, we depend on computational models for the oceanic water temperature near the pipeline. For volume assessments the temperature computations uses statistical data giving a equitably accurate estimation of the average temperature in a specified month. For more details check (Hendriks, Postvoll, Mathiesen, Spiers and Siddorn, 2007). The modelled bottom sea floor level temperatures used are the outcomes of oceanographic and climatologic computational models. Typically, this information is provided by external sources.

2.5.1. Heat storage

While using steady-state heat transfer it is presumed that heat transfer between gas and ambient could be expressed as a function of the temperature difference between the gas and the ambient condition, and a persistent heat exchange coefficient. This coefficient interpretes for the thermal resistance of the pipeline and surroundings. This assumption is only precise during true steady-state operation of the pipeline. In all further cases there will be a time depending on heat accumulation in the pipeline wall and surroundings, which have influences on the heat transfer to and fro the gas.

2.5.2. Heat transfer

The interaction amongst the gas, the pipeline, and the ambient is typically modelled by assumption of one-dimensional pipe, and modelling steady-state heat transfer with a general heat transfer coefficient, U. [5]

The complete heat transfer coefficient was calculated based on the surrounding soil, the combined thermal resistance of the pipeline wall layers, and convective heat transfer coefficients at the thermal boundaries. Usually, the thermal properties of the pipe wall are recognized when the pipeline is built, and one has characteristic values for the thermal properties of the seabed soil. Burial depth on the other hand has to be firmed once the pipeline is laid on the bottom sea floor.[2]

2.6. The influences of the ambient temperature on compressor installation

Fig. 2.7 compressor station

A lot of water and oil in compressor installation and products higher ambient temperatures have an influence on the amount of moisture in the air tense into the installation. For instance, there is more than double as much moisture in the air at 36°C (max. 42 gr/m^3) than there is at 19°C (max. 16 gr/m^3). It is therefore important that the installation is in impeccable condition and connected to the exact type of dryer.

2.6.1. Air conditioning or without air-conditioning

Air conditioning (AC) does not assure a solution to higher ambient temperatures problem. As the compressed air passes through the pipes from warmer compressor room into cool environment, it is unavoidable that condensation will be formed in the pipes if the dryer is not functioning appropriately, resulting in water in the pipes.

And certainly in the situation of air cooled installations, the temperature of compressed air rises significantly, up to 52°C or more. This has an opposing influence on the amount of oil transported in oil lubricated compressors, implicate that more oil vapours are created. Standard filters, which typically specify a filter capacity based on a reference compressed air temperature of 22°C, hardly remove these vapours.

2.6.2. Higher loads subjected to compressors

In an amount of industrial processes, the compressed air volume is specified in Normal cubic meters (Nm^3) at an orientation temperature of 0°C. This reference shows the number of molecules in 1 Nm^3, which is essential when using air separation units or during chemical process.

However, the compressor draws in an ambient air at a considerably higher ambient temperature, the installation has to work harder (so therefore, more rotations/loaded hours) to produce the same amount in Nm^3. Consider it as a balloon that you have inflated. Leave it in the sun and it will enlarge; leave it in a freezer and it will shrink. In order to produce the same capacity, you would have to inflate more balloons in the sun.[1]

Experience has trained us that it does not take too long for many compressor housings to reach high temperatures of up to 55°C during the summer periods. If the compressor does not get a separate intake channel, it will be working nearly 14% harder to achieve the same sum in Nm^3 than when sucking in air at a temperature of around 20°C. Furthermore, the cooling efficiency of an air-cooler installation reduces at higher ambient temperatures, which simply means that air has to be removed from the installation. It is therefore hard to wonder that it is difficult to operate lots of installations at higher temperatures.

2.6.3. Dirty and Saturated filters

In spring season, nature is in bloom, and even compressors and refrigerating aggregates suffer due to trees and grass pollens. Whenever this pollen is considered before the installation, the nominal volume of the installed cooling apparatus decreases substantially. The combination of this and the higher amount of oil and water in the compressed air puts lots of strain on the compressed air filters. For this motive, the maintenance intervals of the filter installation should be considered. Failing to do so will mean there is a severe risk of the filter breaking down, with undesirable consequences for the end product. Fortunately, there are special indicators (dP) that shows when a filter is saturated. However, for most filters, such as active carbon filters, this is not the situation and the filter volume will be totally negated when the filter is saturated.[3]

2.7. How ambient temperature affects Compressor station aggregates

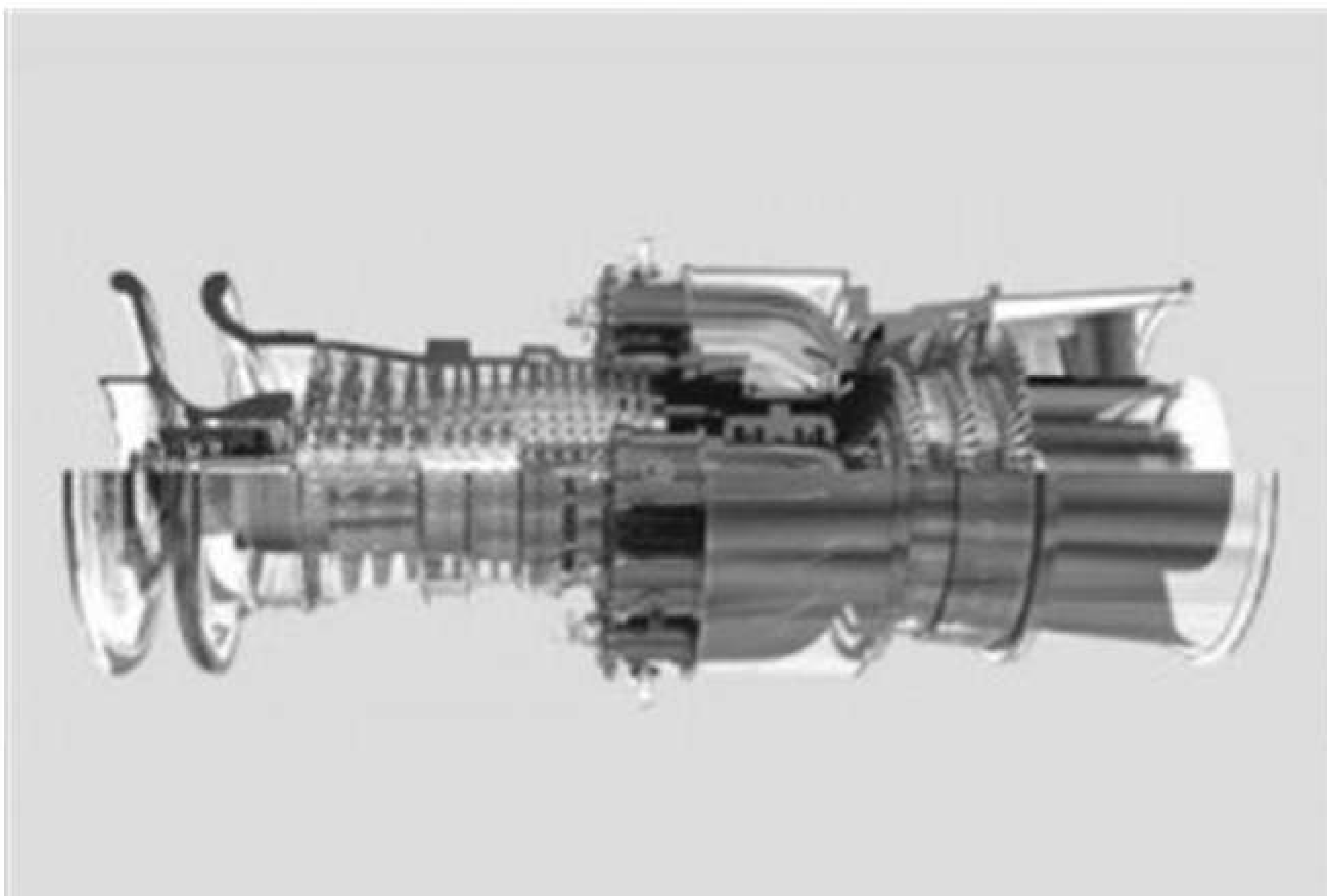


Fig. 2.8. Gas turbine engine

Alterations in ambient temperature have an effect on heat rate and full load power of a gas turbine, but moreover and optimum power turbine speed and part-load performance. Manufacturers characteristically provide performance maps that designate these relationships for ISO conditions.

The quotations are taken from a document "Gas turbine performances" The performance curves are the outcome of the interaction between the different rotational components and control system. This is mainly true for DLN engines. If the ambient or surrounding temperature changes, the engine is subject to the resulting effects: The air density fluctuates. An increased in ambient temperature reduces the density of the inlet air, thus dropping the mass flow rate through the turbine, and also decreases the power output which is directly proportional to the mass flow rate even more. At constant speed, where the capacity of flow remains roughly constant, the mass flow rate will rise with a decrease in temperature and will reduce with an increasing temperature. [2]

The pressure ratio of the most compressor at constant speed gets lesser with increasing temperature. This can be gotten from a Mollier's diagram, showing that the greater the inlet temperature is more work (or head)is required to be achieved a certain pressure increase. The improved work has to be provided by the gas generator turbine, and is thus lost for the power turbine, as can be seen in the enthalpy-entropy graph. At the same time NGgcorr (for instance, the machine Mach number) at constant speed is decreased at higher ambient temperature. As explained in previous, the inlet Mach number of the engine compressor will increase for a specified speed, if the ambient temperature is reduced. The gas generator Mach number will rise for reduced firing temperature at constant gas generator speed.

The Enthalpy-Entropy Diagram illustrates the Brayton cycle for a two-shaft gas turbine. Because the head created by the compressor is proportional to the speed squared, it will not change if the speed remains constant. However, the pressure ratio generated, and thus the discharge pressure, will be lower than before. Considering the combustion process, with a high compressor discharge temperature and since the working temperature is restricted, we see that fewer heat input is possible, ie., lesser fuel will be used .The expansion process has lesser pressure ratio accessible or a larger fragment of the available expansion of work is being consumed in the gas generator turbine, allowing less work to be accessible for the power turbine.

However, on two-shaft engines, a decrease in gas generator speed happens at high ambient temperatures. This is due to the statement that the equilibrium condition between the power requirements of the compressor (which rises at high ambient temperatures, when the pressure ratio should be maintained) and the power produced by the gas generator turbine (which is not directly affected by the ambient temperature as long as compressor discharge pressure and firing temperature remains constant) it will be fulfilled at a lower speed. The lower speed or rotation often cause a reduction in turbine efficiency: The inlet volumetric which flows into the gas generator turbine is gotten from the Q3/NGG ratio and the first stage of turbine nozzle (which is the operating point of the gas generator turbine) therefore goes away from the optimum.[5]

Variable compressor guide vanes permit the gas generator speed is to be constant at higher ambient temperatures, thus escaping efficiency penalties. In a single-shaft turbine, constant gas turbine speed would see a constant head (because the head stays roughly constant for a constant compressor speed), and thus a decreased in pressure ratio. Due to the flow capacity of the turbine section governs the pressure-flow-firing temperature relationship, equilibrium will be set up at a lower flow, and a lower pressure ratio, thus a less power output.

The compressor discharge temperature at constant speed surges with rising temperature. Thus, the amount of heat that could be summed to the gas at a given maximum firing temperature is decreased.

The significant Reynolds number is altered: During full load, single-shaft engines will run a temperature above all ambient temperatures, whereas two-shaft engines will run at temperature topping (at ambient temperatures much higher than the match temperature) or at high speed (the ambient temperatures is lower than the equal temperature). At speed top, the engine will not reach its full firing or working temperature, while at temperature topping, the engine will not reach its ultimate maximum speed. The net influence of higher ambient temperatures is a rise in heat rate and a decreases in power. The impact of ambient temperature is generally less definite for the heat rate than for the power output, because there is changes in the impact of ambient temperature so there lesser element efficiencies than the overall cycle output.

Significance and basic concepts of technical diagnostics of the main gas pipelines.

The effective operation of the main gas pipelines is not possible without the use of modern methods and tools to evaluate the energy consumption for gas transportation, to monitor and predict the technical state and technological parameters of work of the linear part of the main gas pipeline and the CS equipment.

In this regard much attention is currently paid to the creation of means and methods of technical diagnostics.

Technical diagnostics is a field of knowledge, exploring the technical state of objects under diagnostics and the reflection of the technical states in physical units, developing the methods for their determination, as well as the principles of building and organizing the use of the diagnostics system. The technical state in this regard means a set of object properties subject to change during its "life cycle" characterized from time to time by the parameters predicted at the initial stage of design and the set by the normative and technical documentation for an object that form the range and limits of quantitative and qualitative characteristics, which determine the serviceability, normal operation and proper work of the object.

The diagnostics object is a complex of elements subject to diagnostics, connected to the mechanical, gas dynamics, hydraulic and electrical circuits forming a dynamic system, the state of which in every moment of time is determined by the values of input, internal and output parameters, the latter of which reflect the influence of many physical and chemical processes arising from the operation of the object and its interaction with the environment. The serviceability is understood as the condition under which the object is functioning correctly in all modes at all acceptable conditions of work during the specified time. The correctness of operation is the state of the object in which it or its components perform at the current time the operation algorithms assigned to them with the parameter values corresponding to the established requirements.

Changing the technical state of the object is the process of transition of the object from the serviceable to nonservice able state, i.e. up to a “failure” condition, related to the appearance and development of the fault in the elements (systems) of the object up to a certain critical level, after which the object reaches its ultimate state. Technical diagnostics is the process of recognizing the classes of the object's technical state during its "life cycle": from the initial design stage to decommissioning, providing location, causes and the extent of the defects development. It is divided into three stages:

- Technical condition monitoring;
- Localization, degree of development, determination of the failure (faults) reasons;
- Technical condition prediction.

The diagnostics system is understood to be a series of GPU as an object under test, technical facilities for the collection, accumulation, transmission, processing, storage and presentation of information with the relevant software and, if necessary, the performers. In this regard there are the following systems: testing and functional diagnosis. In the first case, the system provides the ensuring specially arranged effects to the object with the subsequent analysis of the object response to these effects. The testing diagnosis systems are used, for example, when studying the GPU under conditions of special test benches. In the functional diagnosis systems the effects provided by the operation algorithm of the object operation are used as the signals (effects). The diagnosis algorithm is understood to be a series of transformations and logical conditions existing in a certain manner and aimed at the faults finding. The efficiency of the diagnosis process depends mainly on the quality of the diagnosis algorithms. The practical experience in creation and implementation of the diagnostics systems suggests that the effectiveness of the diagnosis process is determined not only by the quality of the developed algorithms, but also to a large extent by the quality of diagnosis tools. They can be hardware or software, external or built-in, manual, automated or automatic, specialized or universal. As for the timing aspect the diagnosing tasks are divided into three classes: the diagnosis tasks in real time, the tasks of predictive and retrospective diagnosis. The tasks of real time diagnosis are aimed at recognition of the technical state at the current time. They appear to conclude the guaranteed safe and efficient operation of the object under diagnosis in this case. The tasks to determine the state in which the object under diagnosis will happen to be in a certain future moment of time or to determine the time to a "failure" belong to the predictive diagnosis. These are the prediction tasks arising to establish the secure service life, to determine the terms of carrying out the preventive inspections and repairs, etc. The tasks to determine the state, in which the object under diagnosis was during certain moment of time in the past, belong to the third class. Such tasks related to the reproduction of the technical condition are arising in connection with the investigation of the accidents and their prerequisites. In all cases the awareness of the condition of the object under diagnosis at the present moment is obligatory for the prediction and retrospective diagnosis. The diagnosis tasks are divided into three classes on the principle of the purpose unity: – design and technological and methodological tasks relating to the object under diagnosis and solved on the stages of their design construction; – to develop a methodology of diagnosis and interconnection of diagnostics with the objects of use (the management system of the gas transportation technological process, maintenance and repairing system). The elementary inspection is the testing or working effect on the object and its response to this effect. When diagnosing, for example, the GPU under the operating conditions, the working effects consisting of changing the position of all possible control elements, are used as a constituent of elementary inspection. When diagnosing the gas pumping units under the bench conditions, the use of testing effects by connecting the units and the systems of GPU to the special units is possible. The inverse tasks mean the determination of a certain series of elementary inspections, which allow determining the specific technical state of the object under diagnosis. The solution of the inverse diagnosis tasks allows getting one or all of the possible elementary checks, detecting a possible malfunction of the object. The main parameters and characteristics used in the diagnosis are as follows:

- Duration of diagnosis;
- The reliability of diagnosis;
- The completeness of diagnosis;
- The depth of the failure (fault) localization;
- The conditional probability of undetected failure (fault) during the diagnosis (control);
- The conditional probability of undetected failure (fault) in the given element (group);
- The conditional probability of a fictitious failure (fault) in the given element (group).

Along with the marked concepts in recent years the term "diagnostic maintenance", a series of actions on determination and recovery of technical condition of the diagnosed objects being in operation, which provides the use of human and material resources interacting according to the accepted organizational structure of their distribution, with appropriate provision of diagnostics, is widely used. In turn, a diagnostic assurance is commonly understood as a set of hardware and software diagnostic tools, as well as material and human resources required and sufficient for determination and prediction of the technical condition of the objects under diagnosis with the depth and reliability stipulated by the technical and economic feasibility for the specified conditions and location of the equipment operation. Two groups of diagnosis indicators are set as the main ones. The first group includes the indicators of reliability and accuracy of the diagnosis. [7]

2.8. Conclusion

1. Execute analyse of technological schemes of Nigeria compressor stations which displacement in different regions of country.
2. Execute analyse influence of different ambient conditions at characteristics of main compressor station equipment.

PART 3

TECHNOLOGY FOR GAS TURBINES OPERATING IN HARSH ENVIRONMENTS

Location, site and climate can all have a significant influence on the effectiveness and overall power yield of gas turbines. In hot climates, and or at high altitude, gas turbines functioning in single or combined cycles generate less power than their corresponding counterparts working in a cooler environment or near sea level.

Seasonal and daytime weather variations also influence turbine performance. With the demand for power in the Middle East and Southeast Asia growing, turbine professionals have fixated on emerging techniques to improve the efficiency of turbines working in hot and humid climates.

Gas turbines are air-breathing machineries whose power yield is reliant on the air quantity through the compressor. Ambient temperature, elevation and humidity all influence the concentration of air. On warm days, when air is less dense, power yield drops. Hot and humid air is less concentrated than dry, cooler air and the density is thinner at great altitudes. As the density of air reduces, more power is requisite to compress the same mass of air. This decreases the yield of the gas turbine and reduces efficiency. [15]

3.1. Methodology and examination of climate conditions on aggregates

3.1.1. Modelling information

Natural gas, a progressively prevalent source of energy, is conveyed from source to sink by numerous means including pipelines. Gas pipelines span hundreds to a couple thousand kilometres and could have a variety of capacities (specified by the gas flow rate) and restricted by, among other things, pipeline diameter. However, to attain desired gas flow in pipelines, the kinetic energy gas molecules initially possess at the well-head must be replaced as it is reduced in transit primarily because of frictional losses. Pipeline pressure reloading points are called compressor stations (CS) and house appropriately sized compressors. For two gas pipelines in Nigeria, the Oben-Ajaokuta (billed for upgrade) and the proposed Ajaokuta-Abuja-Kaduna pipeline, conducted a CS location and compression power requirement analysis. Given the results obtained by, this work makes a selection of gas turbines for use as CS drivers at the numerous sites taking into account the peculiarities of the CS locations.

Because gas turbines (GTs) are rated at ISO conditions of 15 °C and 101.3 kPa [4], their performance within the context of power yield and efficiency is greatly affected by functioning ambient conditions of temperature and pressure. Ambient temperature is the most swaying factor of the lot as shown in several literature involving studies on the effect of ambient conditions on GT performance. For instance, [6], [7] opine that for every °C rise in temperature above the ISO standard, GT power output decreases by 0.5–0.9% according to its size and other features. Also, thermal efficiency of a GT engine is negatively impacted when the machine works in climes with temperatures above the design conditions. An empirical study of the SGT 94.3 by [8] reached the conclusion that thermal efficiency drops by about 0.1% for every K rise in ambient temperature. Power losses as ambient temperature rises are not peculiar to medium/large scale gas turbines. Microturbines (with power output ranging from 25 to 500 kW) also experience performance decline at increased ambient temperatures. developed a simulation code, based on experimental data, and studied the performance of a 100 kW machine and reported a 1.22% reduction of electrical power output per degree rise in ambient temperature above ISO conditions.

These superficially small reductions in GT performance can amount to a lot in hot areas like Nigeria where temperatures of in excess of 30 °C are not unusual. The consequence of ambient air pressure (occasioned by altitude) are not quite as much as that of temperature variations especially for land-based GTs [10]. However, ambient pressure does affect the performance of GTs and for an all-inclusive approach to GT selection, the effect of pressure must be accounted for as well. To upgrade machine performance, numerous turbine inlet air cooling methods have been constructed and applied. A more innovative method by [11] substitutes throttle valves at natural gas pressure relief stations with turbo expanders that make use of the potential cooling and power capacity of such stations that is otherwise unexploited. The economics and choice among a number of inlet air cooling systems including inlet chilling and inlet fogging has also been comprehensively examined by works such as [12], and found to be mostly location-dependent.

Aside the employment and effect of inlet air cooling, GT performance denigrates as turbine component depreciates over time. The efficiency of the GT separate components, predominantly the compressor, combustor and turbine defines the overall performance of the machine [15]. Degradation in any one of these components will, consistently, impact engine performance. Since deterioration is eventually unavoidable, and presents itself as added losses and decreased flow capacity, it has been accounted for in this work by upsetting the turbine compressor with a concurrent 3% reduction in flow capacity and 1% decrease in efficiency – one of the extreme acceptable cases of GT engine degradation.

In this work therefore, the factors influencing GTs in the exact locations of the gas pipeline compressor stations are examined. Five GTs within the preferred compression power requirement range are designed similar to existing machines and their performance along the Oben-Ajaokuta and the Ajaokuta-Abuja-Kaduna pipeline route simulated. The precise aim is to develop operational data that will help in the choice of GTs as CS drivers along the pipeline route.

3.2 Modelling of atmospheric condition for various regions in Nigeria

Models of 5 industrial gas turbines, rated within the CS power requirement range for the two gas pipelines, were created using TURBOMATCH and PYTHIA (Cranfield University's in-house gas turbine modelling and simulation software). All five machines chosen for study, are two-shaft gas turbine engines comprising of a gas generator and a free power turbine and have been dubbed TS1, TS2, TS3, TS4 and TS5 in order of increasing size. Studies have confirmed that two-shaft engines like the ones chosen are better than single shaft engines for mechanical drive usages. The key cause is because unlike single shaft engines, the gas generator speed of two-shaft engines is not dependent on that of the driven load hence it is more suitable to handle power demand fluxes. A schematic of the created models is shown in Fig. 3.1.

Performance data (at ISO conditions) for developing models were attained from public domain on OEM websites of similar machines. In particular, TURBOMATCH was employed for design point and off-design simulation of chosen gas turbine engines. Through an iterative technique as elaborated in Fig. 2, TURBOMATCH corresponded with the several engine components satisfying the required conditions of compatibility of mass flow, work and rotational speed [2]. For example, the mass flow accessible for the free power turbine is same as that exiting the gas generator; the power turbine pressure ratio is stable by the gas generator turbine and compressor pressure ratio. Calculated parameters have been paralleled with published OEM data (Fig. 3) and show an accuracy of over 99% in all cases.[3]

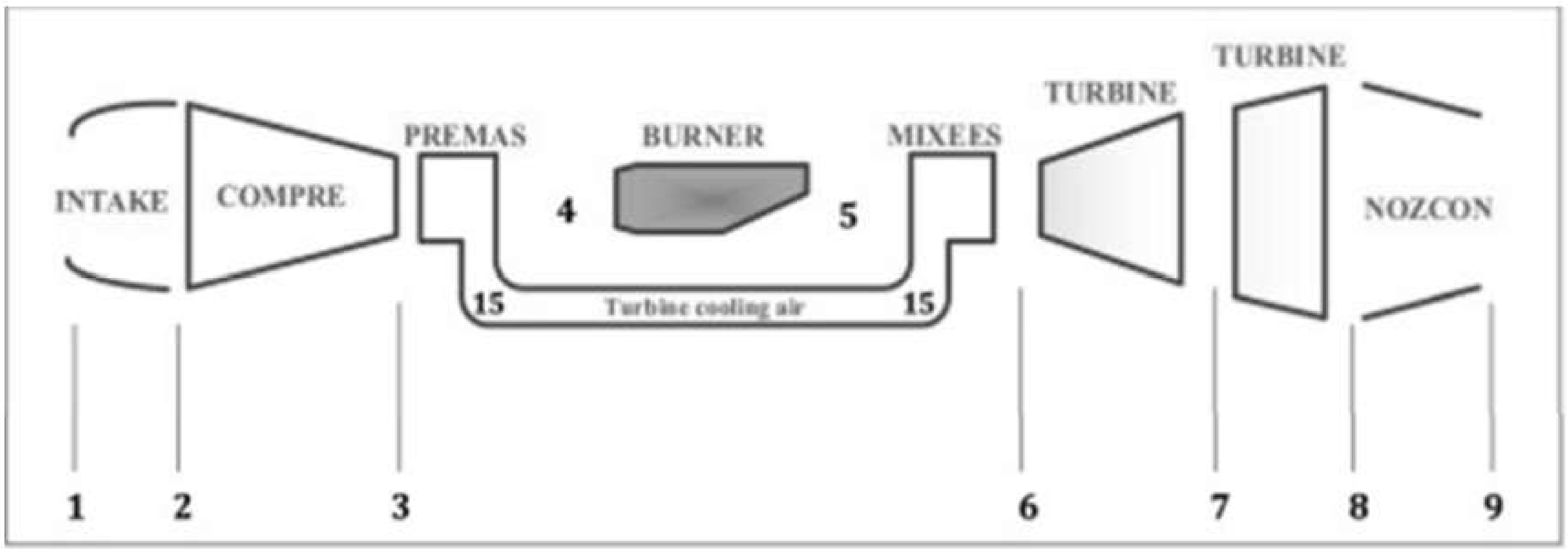


Fig. 3.1- Engine model schematic for selected gas turbines.

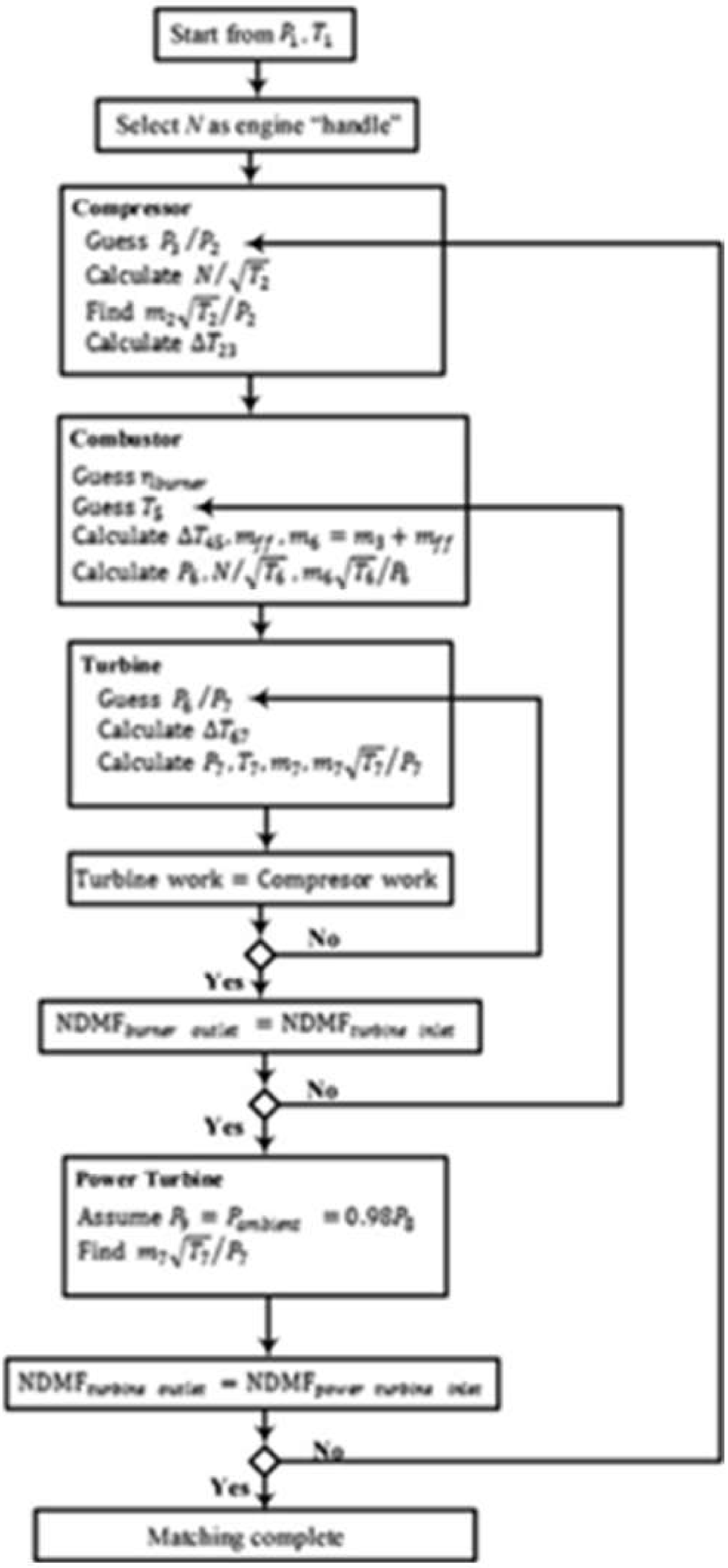


Fig. 3.2- data input

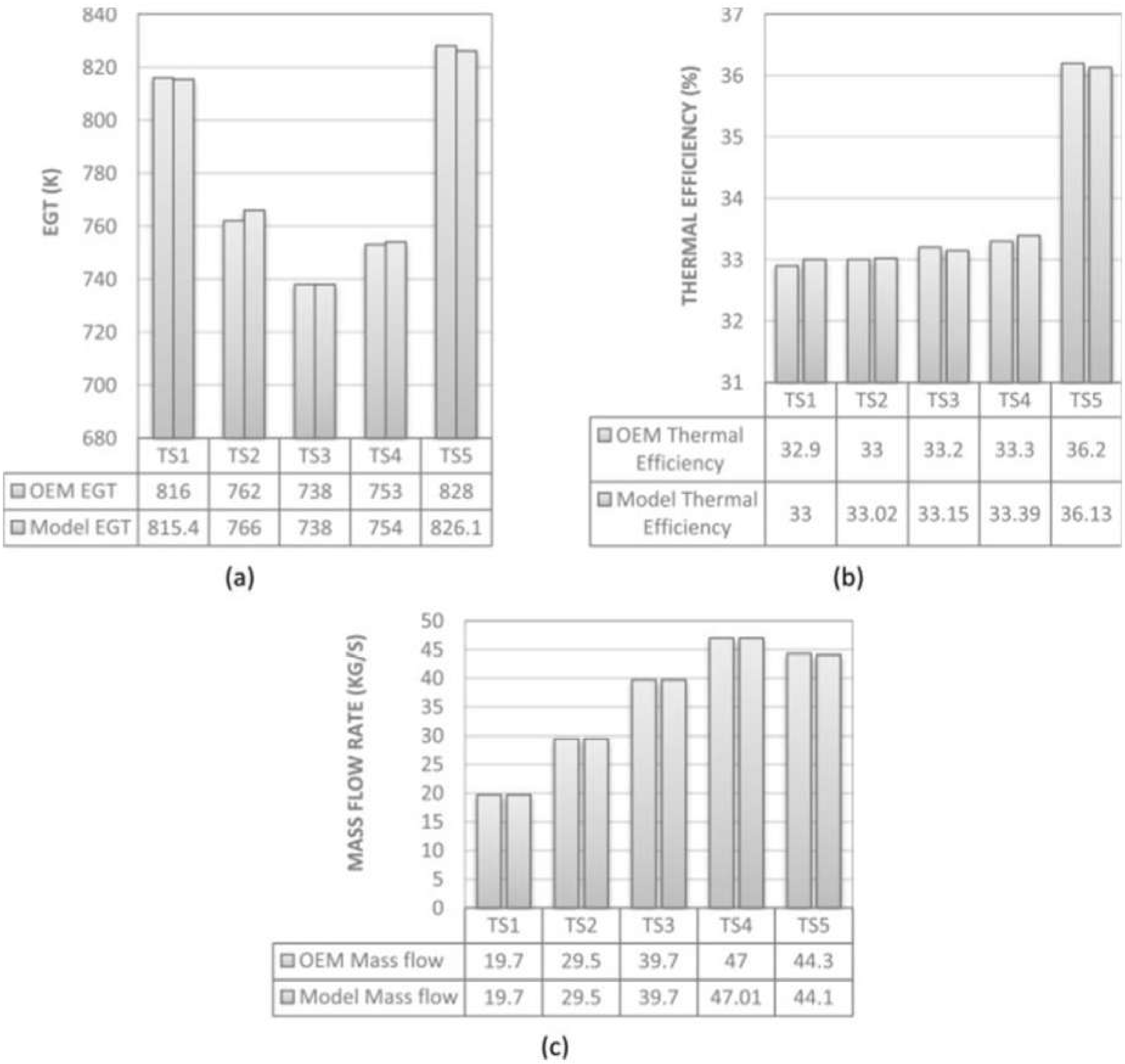


Fig. 3.3- Parameters of model and real engine compared at design point (a) EGT (b) thermal efficiency (c) engine mass flow.

PYTHIA was used to investigate the turbine performance under deteriorated conditions and ambient condition. The major assumption made when using the PYTHIA doftware code for deterioration research is that the degradation of compressor flow volume is equal in magnitude as the degradation of compressor pressure ratio. An exact method of measuring compressor inlet flow for gas turbine engines operating in the field has yet to be achieved. However, using inlet depression measurements to indicate compressor flow, and using computer simulations, reported a fairly equal percentage change in compressor pressure ratio degradation and flow capacity decrement as a consequence of fouling. As an assumption then, in the PYTHIA code, if compressor flow capacity is perturbed by −3%, compressor pressure ratio is simultaneously perturbed by −3%.

The GT cycle, and as employed by TURBOMATCH, is a continuous flow process governed by the steady flow energy equation [5] given as:

$$Q-W=\Delta H \quad (3.1)$$

where Q and W represent, respectively, the heat input and work output of the system and ΔH, the change in enthalpy, represents the change in energy of the gas in the system. Assuming the working fluid is an ideal gas with constant composition throughout the entire control volume [25], the change in enthalpy can be expressed as:

$$\Delta H=m\times cp\times\Delta T \quad (3.2)$$

The adiabatic compression work required by the compressor is given by Eq. (3) where mair is the mass flow rate of air at station 3, the flow rate from the compressor.

$$W23=maircp,air(T_3-T_2) \quad (3.3)$$

And the compressor outlet temperature for assumed isentropic compression is given by:

$$T3=T2(P3P2)\gamma-1\gamma \quad (3.4)$$

The actual compressor discharge temperature taking into account the isentropic efficiency (ηc) of the compressor [15], and using engine notations as in Fig. 1, is given by:

$$T3=T2+T2\eta c[(P3P2)\gamma-1\gamma-1] \quad (3.5)$$

Compressor discharge air is split into primary and secondary uses so that there is no difference between P3 and P4. The primary air undergoes combustion whereas the secondary type is used for turbine blade cooling to help improve turbine blade life. 2.5% of the total air mass flow was assumed to be bled for cooling in this study. The assumed quantity of bled air is practicable and represents approximately the simulated amount of fuel burned in the machine so that flow compatibility between compressor and turbine is maintained. Moreover, a combustor pressure loss of 5% (of compressor delivery pressure) was factored into the simulation for all five machines.

$$P5=P6=0.95P3 \qquad (3.6)$$

Similar to Eq. (3), the adiabatic expansion work in the gas generator is given by Eq. (7) where mgas is the charge flow rate at station 6 – the sum of the compressor outlet flow and fuel flow.

$$W67=mgascp(T6-T7) \qquad (3.7)$$

Since the gas generator turbine drives the compressor, the work output by this turbine is assumed equal to the work requirement of the compressor so that W23 and W67 are equal hence T7 can be obtained. The gas turbine exit pressure can then be determined from Eq. (8) taking into account the isentropic efficiency of the turbine, ηt.

$$T7=T6-T6\times\eta t[1-(P7P6)\gamma-1\gamma] \qquad (3.8)$$

Applying the same isentropic correlation to the power turbine unit and assuming a 2% pressure loss in exhaust nozzle, the gas exit conditions can be determined as follows:

$$P8=P9(\text{ambient pressure})0.98 \qquad (3.9)$$

$$T8=EGT=T7-T7\times\eta pt[1-(P8P7)\gamma-1\gamma] \qquad (3.10)$$

From the foregoing and still using the station numbering of Fig. 1, the heat input to the combustor Qin, the useful work output (from the power turbine) W78 and the efficiency of the machine, ηth can be estimated by Eqs. (11), (12), (13).

$$W78=UW=mgascp,gas(T7-T8) \qquad (3.11)$$

$$Qin=mgascp,gas(T5-T4) \qquad (3.12)$$

$$\eta th=UWQin \qquad (3.13)$$

3.4. Bucket being coated using thermal barrier coating by means of an air plasma spray gun

Gas turbine engine manufacturers identify performance at standard conditions known as ISO ratings. The three main or standard conditions identified in the ratings are Relative Humidity 60 per cent, Ambient Temperature 15°C, and Ambient Pressure at Sea Level. Gas turbine efficiency declines by 1 per cent for every 10-degree increase in temperature more than the ISO conditions. Depending on the gas turbine, this transforms into a power output decrease of 5 to 10 per cent. [13]

3.4.1. Inlet air cooling systems

Since the last 30 years in an effort to compensate for the lesser air mass at high temperatures, gas turbine manufacturers have presented methods to cool inlet air, thus boosting turbine output results in single and combined cycle operations. Providing cooler air into the turbine increases mass flow, resulting in higher output result. The power necessary to compress air is directly proportional to the temperature of the air, so decreasing the inlet air temperature decreases the work of compression and there is more power accessible at the turbine output shaft result.

Three main kinds of system are accessible: overspray techniques (wet compression or high fogging), chiller technology and evaporative cooling. During evaporative cooling, water is filtered through a porous medium to cool the air. Evaporative cooling is not very effective in conditions with slightly high humidity. Water is not injected onto the system.

During fogging system, water droplets are squirted in the air to artificially create colder conditions. The water quickly evaporates in the air inlet before getting to the compressor. During inlet fogging or wet compression, a fine spray of demineralized water go into the compressor, where it evaporates. Overspray and Fogging systems require a lot of water than evaporative cooling. In some areas where water is short of supply, other methods may be more suitable.

Each has benefits and drawbacks and it takes site-specific investigation on number of factors to determine combination of technologies or the optimum technology.

Air inlet cools the air by freezing. It is power-hungry but may be economic in circumstances where cheap power or off-peak can be used.

Turbine expert Sasha Savic of S S& A Power Consultancy depicts on wide-ranging practise to carry out the complex process. He begins by researching conditions at the site, including weather arrays and the obtainability of water. The next step is to study the technology installed – as, for instance, some gas turbine technology is more prone to compressor corrosion and erosion than others, in this situation it may be essential to limit the quantity of water injected. Also the all-important economic aspects, for example, the added value from investment and capital investment, must be evaluated. It is essential to look at the payback as consumers have different prices, boundary conditions, payback times and capacity.

In the Nigeria, ambient temperature is very high during the summer period, sometimes when peak demand (particularly for air conditioning) is at its highest. Wet compression is one of the accessible methods for inlet air cooling. It can be retrofitted to current frames as well as supplied with fresh systems. It works better in a very hot dry climate, but is effective in high humid surroundings.

Wet compression rises the power output result of the gas turbine by decreasing compressor inlet temperatures, inter-cooling the compressor and rising mass flow rate throughout the turbine. [13

Demineralized liquid such as water is injected into the compressor. It evaporates into the air intake and intensifies the saturation of air, which increases the mass flow rate, leading to additional volume. Wet compression systems can be switched on and off easily, enabling a rapid rise of output peak demand.

Retro fitting wet compression to existing turbines needs some alterations to the plant (for example, coating compressors with more advanced coatings), but it allows the addition of volume without civil work such as addition of generators and extra transformers. When in place, the inputs for wet compression are often demineralized water and power to run the progressing pumps. The water vanishes in the compressor and could not be recovered, so the method is particularly suitable to power plants running together with desalination facilities.

"The system has many profits here in the Gulf area. It is very sustainable technology which is self-determining of ambient temperature and of humidity,".

Operator's decisions about power plant improvements will be grounded on economic, technical and financial considerations. On the technical side, any power plant being considered for improvements must be independently assessed and a step-by-step check of plant components carried out.

"First of all, we define the amount of water which can be sprayed in the unit, depending on the frame, the site-specific boundary conditions and the history of the unit, including reports from previous outages. We look at casing limitations and condition of blades and vanes at the last inspection.

"We check maximum fuel supply pressures which can be delivered; check if there are any boiler limitations in terms of additional exhaust energy. We look at steam turbines and steam turbine generators and calculate their capability to accommodate the additional capacity generated by wet compression. We calculate maximum and minimum temperatures, and look at the generator electrical side and transformers to check that an additional 15 per cent can be accommodated."

If the plant is suitable, wet compression technology can be fitted to the unit during a regular plant outage without affecting outage duration.

3.4.2. Improving designs

During the design of a new or upgraded gas turbine model, the major OEMs take into account the various extreme climatic conditions of their potential markets.

On a hot day the density of air entering the compressor is less than on a cold day. Thus, during summer days, the compressor has less mass flow than the gas turbine capable of utilizing. By installing an oversized compressor, the OEMS can design their systems to utilize unused capability during hot days.

Alap Shah, AVP & Turbine Technologies Manager with Black and Veatch, explains:

"In that case, if you oversize the compressor you can include variable guide vanes in the first few stages of the compressor. Opening the guide vanes passes more volume through the GT and maintains a more or less linear output curve."

This advance may not improve efficiency, but it enables more output at a higher temperature.

Another feature developed for hot climates is thermal energy storage, an extension of chilling inlet air. Chilling inlet air by mechanical chillers or vapour absorption chillers boosts the output of the GT by increasing density at the inlet to the compressor. However, while output goes up, there is a negative impact on the efficiency of the combined-cycle plant considering the auxiliary power consumed by chillers as well as reduced exhaust energy from the turbine.

Shah sees potential in using thermal energy storage for peak shaving, a technique used in a few newly-built combined-cycle plants in the Middle East and North America.

"The concept is to operate the chiller at night [off peak], store the cold energy in a significantly sized tank, and use that cold stored energy during the daytime when you have higher temperatures and higher demand," he explains.

Thermal storage has become popular in the last few years as operating profiles have changed with the integration of renewables. Thermal storage makes good sense when plant is required to operate at peak load during the daytime and to operate at part or minimum load during the night to offset the increase in wind power.

3.4.3. The drive for efficiency

There are other areas for improving turbine performance in hot climates. One is to improve the aerodynamics of compressor technology. Another involves the overall efficiency in the classic turbine technology areas of materials, coatings and cooling. Improving the ability of turbines to operate at very high temperatures drives efficiency and reduces emissions. Work on the combustion system to improve fuel flexibility so that fuels such as shale gases and liquids or unrefined fuels can be burned is another area where work is underway.

Incremental improvements in combined-cycle technology and operations have seen overall combined-cycle efficiency rise to a current level of more than 61 per cent. Guy DeLeonardo, general manager for high efficiency gas turbines at GE Power & Water, believes that over the next decade this figure can be increased to 63 or 64 per cent, which will benefit operators in all climates.

Advances in materials, additive technologies and manufacturing techniques can all contribute to developments. For example, 3D printing can reduce the manufacturing costs of components in the latest-generation turbines. GE is now using an innovative manufacturing machine designed to produce cooling holes in gas turbine parts using a pioneering laser-cutting method.

An understanding of how turbines work in specific conditions is key to driving improvements in efficiency and preparing gas turbines for different conditions. GE is proud of its off-grid, full speed, full load testing facility in Greenville, South Carolina that tests its latest gas turbines beyond real-world conditions.

The $200 million test facility enables the company to fully validate its turbines at ambient ranges of -37°C up to 85°C. More than 6000 sensors and instruments collect data on all aspects of operation and components of the gas turbine during validation and more than 8000 data streams are captured continuously during testing. GE says that one unit running for 200 hours in the test facility is more valuable than 500 units in the field running for one year.

3.4.4. Add solar, save fuel

In the US and Spain, solar thermal power stations have been generating electricity for years. Concentrating solar power (CSP) technology is mainly based on the use of parabolic trough collectors, concentrating the solar radiation, heating up a thermal oil and transferring the thermal energy to a boiler generating steam, which then drives a steam turbine.

Additionally, a heat storage system with molten salt can increase operating time even at night. This can be added to a conventional power plant by integrating a burner into the collector field boiler. If there is no solar power (directly or from the storage), the boiler turns into a conventional one, using any standard fuels for steam production.

In a hybrid integrated solar combined cycle power station (ISCC), the first part of the plant is a standard combined cycle driven by a conventional fuel. For example, in the first stage a gas turbine generates the power. In the second stage, the exhaust heat is turned into steam (high temperature and pressure), directly used to feed an additional steam turbine. At the same time, the steam turbine takes additional steam (with low temperature and pressure) from a solar field boiler. Hence the solar collector field directly improves the power outputs of the steam turbine and the whole combined cycle, while storage is also used.

The MENA region's largest SCC plant is the $554 million Ain Beni Mathar project in Morocco. The 160 ha site includes a huge solar field contributing about 20 MW to the total capacity of 472 MW. Hassi R'Mel integrated solar combined cycle power station in

Algeria combines a 25 MW parabolic trough concentrating solar power array, covering an area of over 180,000 m^2, in conjunction with a 130 MW combined-cycle gas turbine plant. Mexico's first ISCC power plant comprises a 464.4 MW combined-cycle power plant and a 12 MW solar field.

"The material to build a solar receiver with its storage at 900°C is not really available in the market. Some small developments have been done, but at lower temperature around 650°C-700°C."

"The objective is to maximize the operating time of the solar share of the combined cycle. Next steps might take another 10 years, but the development of suitable storage material will bring interesting fuel savings," Saidi says.

"Especially for Nigeria, where natural gas is cheap and solar direct radiation capacity is very high, ISCC solutions could then be turned into reality, bringing a lot of benefits."

3.4.5. Monitoring for Safety and Efficiency

Temperature is a determining factor in turbine safety and efficiency. Increases in the turbine inlet improve the engine's efficiency: the turbine can produce the same amount of power with less fuel, or produce more power with the same amount of fuel. Components, however, face very demanding temperature conditions, in particular at the high pressure compressor exit and at the high pressure turbine inlet. If temperatures get too hot, chances of compressor blade failure and serious component damage increase dramatically.

Another important element is flow nozzle measurement. Measurements at the flow nozzle are critical because readings are plugged directly into efficiency calculations in the turbine's control system. During plant commissioning and routine operations, operators rely on flow nozzle measurements to validate performance and verify the efficiency of the turbine.

The key to plant safety and performance is the ability to accurately measure and track temperature, pressure, and flow. Information collected at specific measuring points can be used to:

- Avoid metallurgical failures — Temperatures need to be maintained below the vessel's melting point in order to avoid metallurgical failure. Too-high temperatures can also lead to creep deformation in the rotating blades.
- Determine efficiency and performance — Performance engineers can calculate the efficiency of a compressor or turbine if they know the inlet and exit temperatures, as well as the flow rate at the nozzle. When a gas turbine exhaust is used as heat input to a steam cycle, engineers can also estimate the performance of the heat recovery steam generator (HRSG) by using the temperature and flow measurement of the gas turbine exhaust.
- Detect inefficiencies — High exhaust temperatures and flow changes can be symptoms of a compressor or turbine that is not operating as it should. If a flow measurement device picks up irregularities, the plant operator can perform a diagnostic to identify the underlying causes.
- Calculate residual life — By tracking temperatures over time, engineers can see the temperature history of a component, such as a furnace tube. This history allows them to calculate how much life the component has left and to plan maintenance and replacements.

3.4.6. What and Where to Monitor

In steam turbines, the following parameters are critical and are continuously monitored:

- Barometric pressure
- Steam and steam condensate's flow rate, temperature, and pressure on:
  - The cold reheat
  - The high pressure throttle
  - The hot reheat
  - Low pressure induction sections

- Exhaust pressure

Similarly, in **gas turbines**, the critical parameters routinely checked include:

- Temperature and flow of the exhaust gas
- Pressure and temperature of ambient air
- Temperature at the compressor inlet
- Pressure and temperature of gas fuel

3.4.7. Interlock and Protection in Thermal Power Plant

The over speed protection actuates whenever speed of the rotor exceeds a preset limit causing closure of fuel gas/fuel oil trip shut-off valve. Over-temperature protection the gas turbine unit is protected against any possible damage caused to the machine in the event turbine outlet gas temperature exceeds a predetermined limit. In such case the over-temperature protection system trips the turbine to arrest any further temperature increase. Flame detection and protection Flame detection device avoids accidental flooding of combustors with unburned fuel due to loss of flame or improper combustion. This device is used to detect flame in the combustors and to trip the turbine in case of flame failure. Vibration protection The vibration protection system of the gas turbine unit comprises vibration transducers fitted on various bearing housings and relative shaft vibration transducers at journal bearings. In the event the vibration becomes excessive, the unit will trip to avoid any damage. Lube oil pressure and temperature protection In the case gas turbine lubricating oil pressure drops below a preset low value, the protective system trips the unit. This is to prevent the turbine from being run with inadequate oil supply to bearings and other accessories. Likewise, bearing temperature also trips the unit should the temperature of bearings exceed preset limit. Hydraulic and pneumatic protection In the event of collapse in control oil/air pressure in piping systems, the hydraulic/pneumatic protection system brings vital system components to a safe operating condition and trips the turbine. Electrical interlocks and protections The protections provided for generator, transformers, motors, etc., are against unhealthy system conditions or to isolate faulty equipment from the system to minimize the extent of damage through the fault. In the event any of the electrical protections, linked with the connected generator or connected electrical system, operates it trips the turbine. [13]

3.3. Results and discussion

As temperature increases above the design point of 15 °C, the combined effect of a reduction in air mass flow rate and the increase in compression work causes a drop in power output. The local site annual peak temperature of 37 °C, corresponding to a deviation of +22 °C in ambient temperature from the design value of 15 °C, results in about 17% loss in engine power output for each considered machine as depicted in Fig. 4(a). Further, Fig. 4(b) shows a reduction in thermal efficiency as ambient temperature rises. This triggers a reduction in pressure and temperature ratio. As a consequence, for a constant TET, thermal efficiency (and engine power output) decreases. Also, Fig. 4(b) shows that between 5–6% efficiency is lost when engine operates at about 35 °C indicating a considerable increase in fuel consumption. Consideration of a fixed engine rotational speed is useful because for increased temperatures, higher spool speeds and/or higher TETs will not only be detrimental to fuel consumption but will greatly reduce creep and low cycle fatigue life.

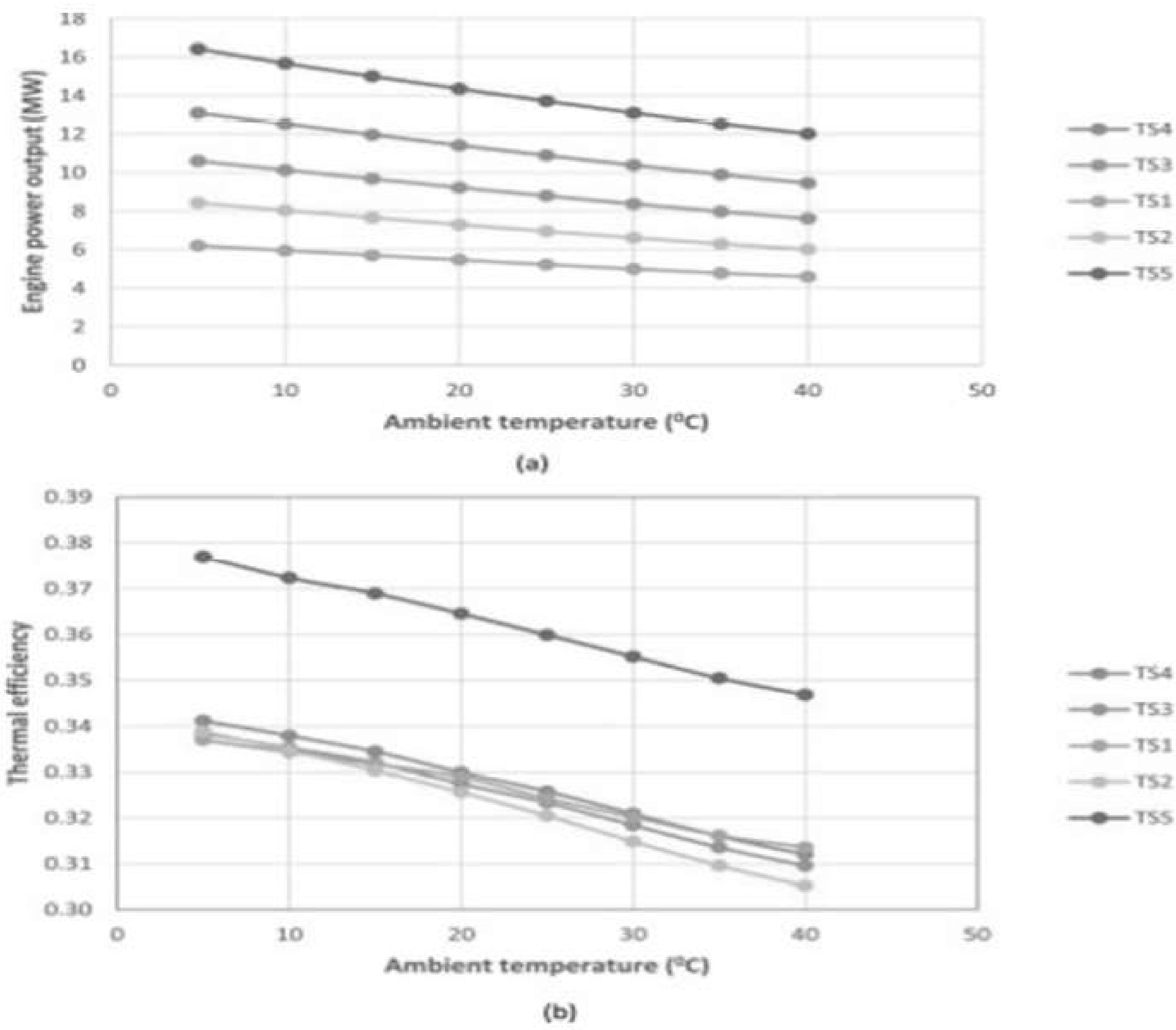


Fig. 3.4- Sensitivity results of effect of ambient temperature on (a) GT power output (b) engine efficiency.

Also, in line with the elevation results obtained by [3] along the pipeline route, the performance of the selected turbines between 0 and 1000 m was simulated and the results displayed in Fig. 5. The average effect of operation at the highest peak along the route, about 1000 m, is a 6% reduction in engine power output. This is as expected since air mass flow rate, a crucial determinant of engine power, decreases with rising altitude. [12]

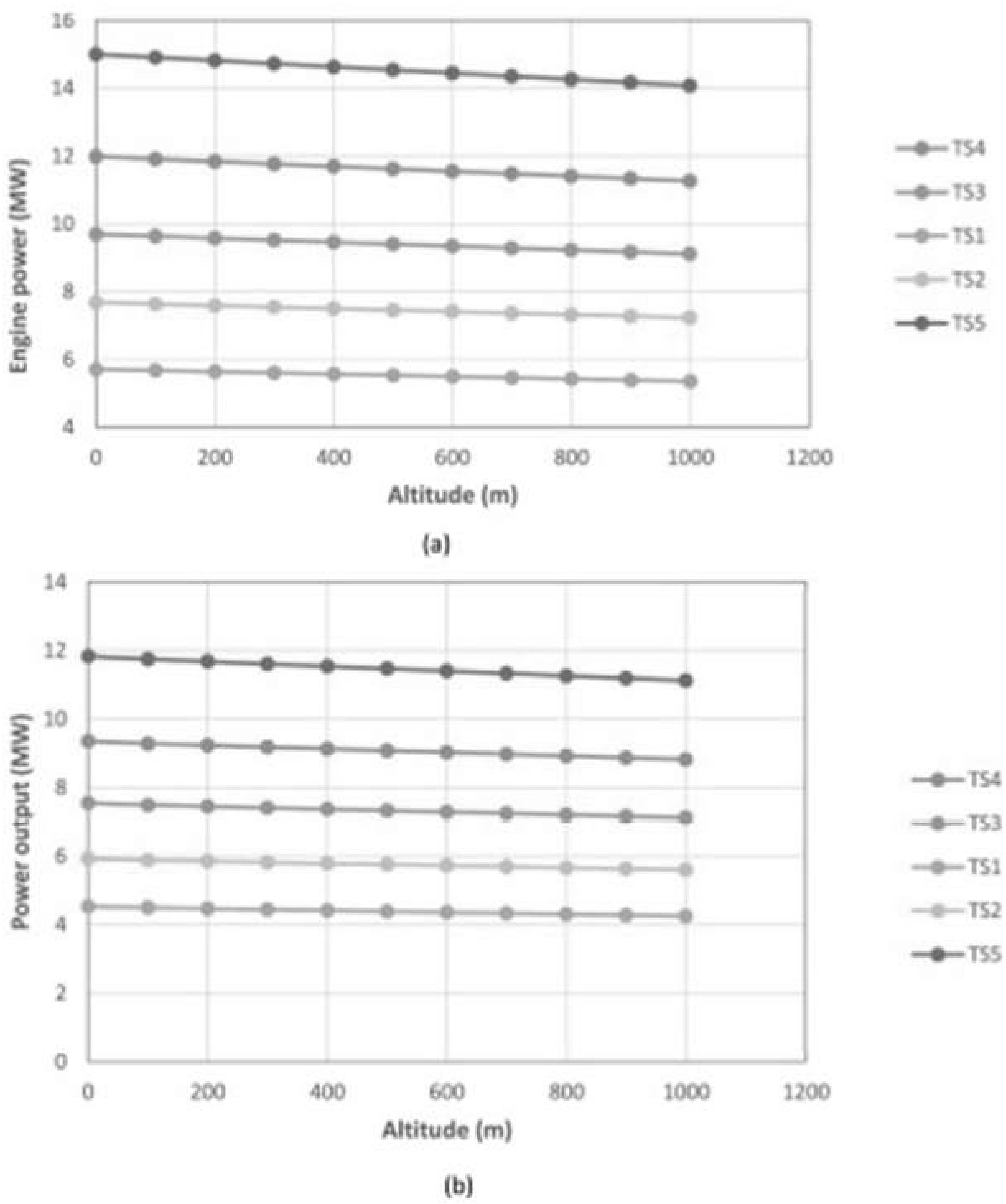
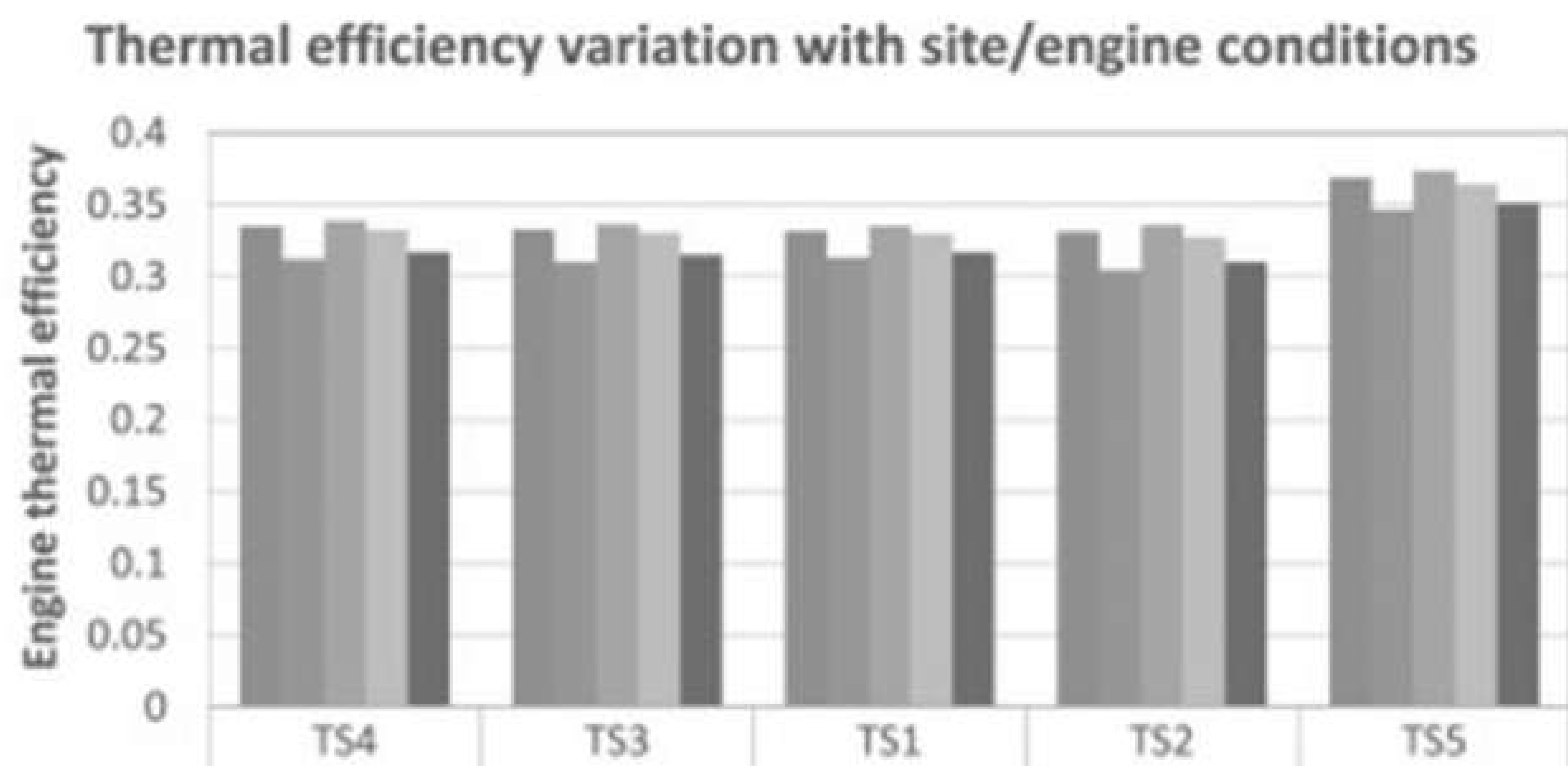


Fig. 3.5- Sensitivity results of effect of altitude on (a) GT power output of clean engine at 15 °C (b) GT power output degraded engine at 37 °C.

Moreover, engine deterioration which is largely a consequence of fouling [7], is known to affect compressor flow capacity and efficiency in particular. The effect on flow capacity always being greater [15]. Fouling distorts individual component characteristics changing measurable parameters like temperatures, flows, pressures and speeds for a fixed engine operating condition. Therefore, the effect on power output and thermal efficiency as a result of a simultaneous 3% reduction in compressor flow capacity and 1% loss in efficiency – one of the extreme allowable cases of compressor fouling – was simulated using PYTHIA.

The combined effect of all three performance-degrading factors – ambient temperature, altitude and deterioration – are presented in Fig. 5(b) and Fig. 6. The average power decrement is 26.3% for this worst case scenario (a combination of the effects of the highest recorded ambient temperature in the region, peak altitude and the allowable extreme case of engine deterioration). The individual power losses are within −0.6 to 1.1% of the average. Therefore it can be safely assumed that any gas turbine rated at least 26.3% more than the minimum power required at any station is suitable at that station. Based on these analysis and the energy requirement and economic study carried out by [3], Table 1 makes a selection of appropriate driver for the subject pipelines. An interesting relationship is found comparing the compression power requirement of the 198 km Oben-Ajaokuta gas pipeline with the 460 km Ajaokuta-Abuja-Kaduna pipeline of 24-in. bore. Approximately 0.04 MW of compression power per kilometre is required for a gas flow rate of 450 MMSCFD, if as in [3], 50 bar is the minimum gas pressure at any point along the lines. Given the peculiar site conditions, and referring to Table 1, 0.05 MW GT drive power per kilometre of pipeline is required as compressor prime mover.



	TS4	TS3	TS1	TS2	TS5
Clean Engine at DP	0.334893	0.332427	0.33147	0.331148	0.368917
Clean engine at 37C	0.312114	0.309902	0.312783	0.30448	0.346297
Clean engine at 1000m	0.339038	0.336503	0.3352265	0.336109	0.373346
Degraded engine at DP	0.332238	0.330333	0.329813	0.327198	0.364597
Degraded engine at 37C/1000m	0.316937	0.314949	0.316876	0.309923	0.350627

Fig. 3.6- Variation of thermal efficiency with site/engine conditions.

Table 3.1- Gas turbine (driver) selection for subject pipelines.

The peak ambient temperature of 37 °C alone causes an average of 6.7% loss in thermal efficiency. At an elevation of 1000 m, there is an average of 0.43% increase in thermal efficiency. The gas generator compressor deterioration acting alone results in an average of 0.9% loss in efficiency. Put together, the effect of these on-site conditions is an average of 5.3% loss in engine thermal efficiency. Thermal efficiency essentially means cost of fuel consumed to bring about desired pressure boost. For gas turbines operating along natural gas pipelines, relatively low thermal efficiency may not be an overriding concern especially if the operator owns the gas being transported. That is often the case so that fuel cost becomes part of internal operating cost. However, if the compressor station operator ships gas from elsewhere, the cost of fuel is impacted and thermal efficiency becomes important. Whatever the case, good thermal efficiency may not be top priority but it is desirable for compressor station drivers since utilisation is near 100% for most periods. In that case, any of the several mechanisms of inlet air cooling may be employed.

The effect of peak site ambient temperature alone is an average of 17% power loss. Altitude and engine compressor deterioration individually result in an average of 6.0% and 3.6% power loss respectively. The overall effect of site conditions on engine thermal efficiency was found to be a loss of 5.3%. The overall effect on power output was a 26.3% decrement. Clearly, the single most power-degrading factor is ambient temperature. Therefore if economically advantageous, inlet air cooling could be adopted in prolonged periods of hot weather. Consequently, barring remedies like any of the mechanisms of inlet air cooling, gas turbines selected for use as CS drivers on the subject pipelines should be rated at least 26.3% more than the minimum power requirement fixed by pipeline gas flow studies.

Conclusion

1. Considered a gas turbine driver solution to compressor stations along the Oben-Ajaokuta and Ajaokuta-Abuja-Kaduna gas pipelines taking into consideration the individual compressor station power requirement and prevailing local site conditions.
2. The effect of ambient temperature including an annual peak of 37 °C in the region was taken into account as was the altitude variation of up to 1000 m. Also, engine deterioration induced by perturbing the turbine compressor with a simultaneous 3% reduction in flow capacity and 1% reduction in efficiency was included in analysis.

Part 4

Labour Precaution

4.1. Safety Hazards Associated with Oil and Gas Extraction Activities

Oil and gas well drilling and servicing activities involve several diverse kinds of equipment and materials. Identifying and controlling hazards is critical to averting injuries and deaths. Some of these hazards are highlighted below. See Standards and Enforcement for more information on evaluation and control requirements.

- Vehicle Collisions
- Struck-By/ Caught-In/ Caught-Between
- Explosions and Fires
- Falls
- Confined Spaces
- Ergonomic Hazards
- High Pressure Lines and Equipment
- Electrical and Other Hazardous Energy
- Machine Hazards
- Planning and Prevention

In the maneuver and maintenance, a GCU worker can operate next perilous and injurious production factors [10]:

- When loading and unloading during assembly and disassembly unit (moving products, billets and materials);
- Unprotected moving parts GCU, lifting machinery and production equipment;
- Vehicles for conveyance of equipment units;
- Destruction and expansion fragments, elements, components invention equipment;
- Amplified slipperiness (due to ice, moisture and lubrication surface installation)
- Increased noise (lessens productivity, rapidly causes fatigue may be due to occupational diseases); [6]
- Elevated levels of vibration;
- Elevated levels of infrared radiation from the heated parts of the drive;

- Elevated levels of ultraviolet radiation and heat;
- Increased dust and fumes in the area of GCU;
- Increased or reduced surface temperature GCU equipment and materials;
- Dangerous voltage levels in an electrical circuit;
- The absenteeism or lack of sunlight;
- The lowered contrast with the background objects distinction;
- Lethal substances (gas, which is used as fuel and as an object of compression);
- Physical overload (static and dynamic);
- Neuropsychiatric (emotional).

Working GTU has an initial temperature of the gas before the gas turbine. At this temperature, the working standard takes considerable heating of body parts and piping, a large amount of heat is released into the environs. It is therefore obligatory to provide adequate protection against heat dissipation [18].

Noise and vibration are also critical. The manifestation of noise causes a decline in performance and impaired hearing. Noise in the control room is aerodynamic and mechanical nature. Mechanical noise created by collisions of several parts of the turbine (noise in the bearings).

Aerodynamic noise generated by high-speed flow of the working fluid. For typical operation, the noise should not exceed some range.

The occurrence of vibration turbine plant has a detrimental effect on the central nervous system staff [4].

4.2. Main Standards and Enforcement for evaluation and control requirements

4.2.1. Vehicle Collisions

Workers and equipment are compulsory to be transported to and from well sites. Wells are often located in remote areas, and require traveling lengthy distances to get to the sites. Highway vehicle crashes are the foremost cause of oil and gas extraction worker's fatalities. Roughly 4 of every 10 workers killed on the job in this industry are killed as a result of a highway vehicle incident (Census of Fatal Occupational Injuries). The following OSHA and NIOSH documents provide guidance on distinguishing and controlling vehicle-related hazards:

- Motor Vehicle Safety. OSHA Safety and Health Topics Page. Addresses hazards, controls and standards related with motor vehicles.
- Work Zone Traffic Safety. OSHA QuickCard™ (Publication 3267). Covers traffic safety in brief.
- Fatal Facts, Oil Patch No. 1-2012. Report on a fatality attributable to a vehicle hazard.
- Motor Vehicle Safety. National Institute for Occupational Safety and Health (NIOSH) Workplace Safety & Health Topic. Lists NIOSH publications and current research into occupational motor vehicle safety.
- Work-Related Roadway Crashes: Prevention Strategies for Employers. U.S. Department of Health and Human Services (DHHS), National Institute for Occupational Safety and Health (NIOSH) Publication No. 2004-136, (March 2004). Provides statistics on work-related vehicle mishaps and prevention options for employers. [2]
- How to Prevent Fatigued Driving at Work – These fact sheets for employers and workers have information about fatigue and how to stay safe behind the wheel. They are also available in Spanish.
- Oil and Gas Well Drilling and servicing eTool: Transportation Module. Reviews potential threats and possible solutions for transporting personnel and equipment, vehicle manoeuvre at the well site, and all-terrain vehicles and utility task vehicles.
- Drive Safe. (September 2019). Video developed by Helmerich & Payne to stimulate safe driving in oil and gas extraction industry.

4.2.2. Struck-By/ Caught-In/ Caught-Between

Three of every five on-site fatalities in the oil and gas extraction industry are the product of struck-by/caught -in/caught-between hazards (OSHA IMIS Database). Workers might be exposed to struck-by/caught-in/caught-between hazards from multiple sources, including moving vehicles or equipment, falling equipment, and high-pressure lines. The following OSHA and NIOSH documents provide guidance on recognizing and controlling these hazards:

- Crane, Derrick, and Hoist Safety. OSHA Safety and Health Topics Page. Addresses hazards, controls, and standards associated with cranes, derricks, and hoists.
- Struck-By. OSHA's Harwood Grant Training Materials. Covers struck-by dangers in the oil and gas industry.
- OSHA Fatal Facts, Oil Patch No. 2-2012. Report on a fatality attributable to a struck-by hazard.
- OSHA Fatal Facts, Oil Patch No. 3-2012. Report on a fatality attributable to a struck-by hazard.
- Guidelines on the Stability of Well Servicing Derricks. OSHA Directive STD 03-12-003 [PUB 8-1.8], (July 15, 1991). [6]

4.2.3. Falls from ladder

Workers might be required to access platforms and equipment situated high above the ground. OSHA requires fall shield to prevent falls from the mast, drilling platform, and other elevated equipment. The following OSHA and NIOSH documents provide guidance on recognizing and controlling this hazard:

Fig. 5.1 fall

- Fall Protection. OSHA Safety and Health Topics Page. Addresses fall control and specific criteria for general industry and construction.
- Fall Protection in General Industry. OSHA QuickCard™ (Publication 3257). Covers fall protection in brief.
- Falls. OSHA's Harwood Grant Training Materials. Covers sources of slips, trips, and fall hazards in the oil and gas industry.
- Walking and Working Surfaces and Fall Protection. OSHA's Harwood Grant Training Materials. Covers slips, trips, and fall hazards in the oil and gas industry and associated OSHA criteria.
- OSHA Fatal Facts, Oil Patch No. 4-2012. Report on a fatality attributable to this hazard. [12]

4.2.4. Confined Spaces

Workers are often required to enter confined spaces such as petroleum and other storage tanks, mud pits, reserve pits and other excavated areas, sand storage containers, and other confined spaces around a wellhead. Safety hazards associated with confined space include ignition of flammable vapors or gases. Health hazards include asphyxiation and exposure to hazardous chemicals. Confined spaces that encompass or have the potential to contain a severe atmospheric hazard must be classified as permit-required confined spaces, tested prior to entry, and constantly monitored. The following OSHA and NIOSH documents provide guidance on identifying and controlling this hazard:

- Confined Spaces. OSHA Safety and Health Topics Page. Addresses specific criteria for the general industry and shipyard employment.
- Permit-Required Confined Spaces in General Industry. OSHA QuickCard™ (Publication 3214). Covers confined space entrance in brief.
- Confined Space. OSHA's Harwood Grant Training Materials. Covers confined space entry in the oil and gas extraction industry.
- Permit-Required Confined Space Entry. OSHA's Harwood Grant Training Materials. Covers confined space entry in the oil and gas extraction industry.

- Confined Spaces. National Institute for Occupational Safety and Health (NIOSH) Workplace Safety & Health Topic. Lists NIOSH journals and current research into confined spaces.

4.2.6. Ergonomic Hazards

Oil and gas workers might be exposed to ergonomics-related injury risks, such as lifting weighty items, bending, reaching overhead, pushing and pulling heavy loads, working in awkward body postures, and performing the same or similar tasks repeatedly. Danger elements and the resulting injuries can be minimized or, in many cases, eliminated through interventions such as pre-task planning, use of the precise tools, appropriate placement of materials, education of workers about the risk, and early recognition and reporting of injury signs and symptoms. The following OSHA and NIOSH documents provide guidance on recognizing and controlling these dangers:

- Strains and Sprains. OSHA's Oil and Gas Well Drilling and Servicing eTool. Lists solutions for preventing strains and sprains in the oil and gas industry.
- Ergonomics. OSHA Safety and Health Topics Page. Covers related standards and guidelines for preventing ergonomic injury.
- Ergonomics and Musculoskeletal Disorders. National Institute for Occupational Safety and Health (NIOSH) Workplace Safety & Health Topic. Lists NIOSH publications and current research into ergonomics.

4.2.7. High Pressure Lines and Equipment

Workers might be exposed to hazards from compressed gases or from high-pressure lines. Internal erosion of lines might result in leaks or line bursts, exposing workers to high-pressure hazards from compressed gases or from high-pressure lines. If connections securing high-pressure lines fail, struck-by hazards might be created. The following OSHA documents provide guidance on recognizing and controlling these hazards:

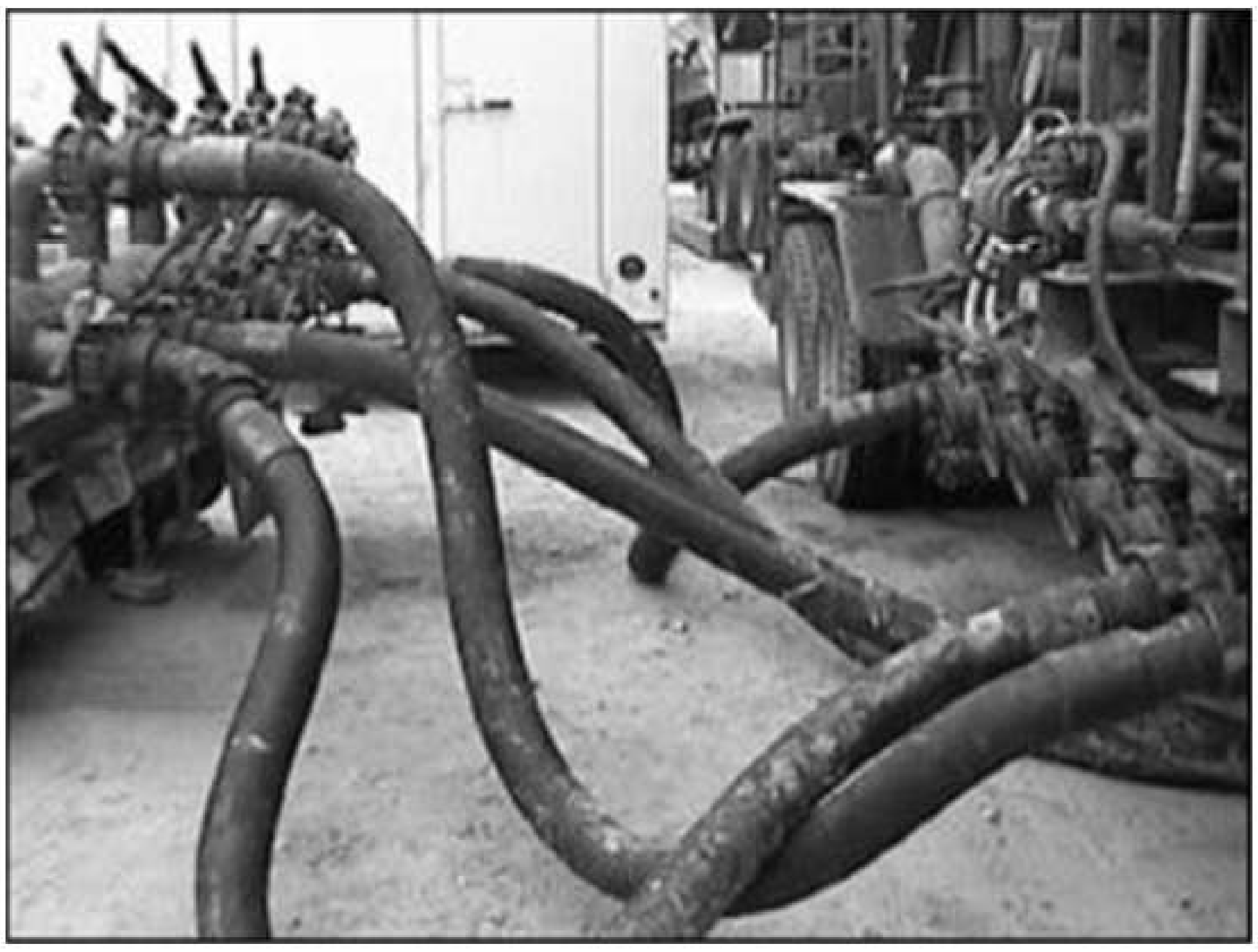


Fig. 5.2. High pressure lines

- Compressed Gas and Equipment. OSHA Safety and Health Topics Page. Reviews standards and hazard-control measures related with compressed gas and equipment.
- Pressure Vessels. OSHA Safety and Health Topics Page. Reviews standards and hazard-control measures associated with pressurized tanks and containers. [6]

4.2.8. Electrical and Other Hazardous Energy

Workers might be exposed to uncontrolled electrical, mechanical, hydraulic, or other sources of hazardous energy if equipment is not designed, installed, and maintained properly. Further, administrative controls such as operational measures must be established and implemented to ensure safe operations. The following OSHA and NIOSH documents provide guidance on recognizing and controlling these hazards:

- Control of Hazardous Energy (Lockout/Tagout). OSHA Safety and Health Topics Page. Reviews general industry principles, explains lockout/tagout concepts, and provides guidance on developing a lockout/tagout program.
- Hazardous Energy. OSHA's Harwood Grant Training Materials. Covers control of lethal energy in the oil and gas industry.

- Lockout/Tagout. OSHA's Harwood Grant Training Materials. Covers control of harmful energy and lockout/tagout measures in the oil and gas industry.
- Electrical Safety. National Institute for Occupational Safety and Health (NIOSH) Workplace Safety & Health Topic. Lists NIOSH journals and current enquiry into occupational electrical safety.

4.2.9. Machine Hazards

Oil and gas extraction workers may be exposed to a extensive assortment of rotating wellhead equipment, including top drives and Kelly drives, drawworks, pumps, compressors, catheads, hoist blocks, belt wheels, and conveyors, and might be incapacitated if they are struck by or caught between unguarded machines. The following OSHA and NIOSH documents provide guidance on distinguishing and controlling these hazards:

- Barrier Guard for Drawworks Drum at Oil Drilling Sites. OSHA Hazard Information Bulletin, (July 13, 1995). Highlights the need for barrier guards for drawworks drums to prevent caught-between dangers at oil drilling sites.
- Caught-Between. OSHA's Harwood Grant Training Materials. Covers sources of caught-between hazards at oil and gas drilling sites.
- Machine Guarding. OSHA's Harwood Grant Training Materials. Covers principles of machine guarding in the oil and gas industry and connected OSHA standards.
- Machine Safety. National Institute for Occupational Safety and Health (NIOSH) Workplace Safety & Health Topic. Lists NIOSH journals and current enquiry into occupational machine safety.

- API 54 Recommended Practice for Occupational Safety for Oil and Gas Well Drilling and Servicing Operations
- API 74 Recommended Practice for Occupational Safety for Onshore Oil and Gas Production Operations

- API 11ER Guarding of Pumping Units. (ANSI/API RP 11ER-1992) (Consist of Supplement 1, July 1, 1991).
- IADC Hand Safety & Injury Prevention for the Oil and Gas Industry

4.3. Explosions and Fires

Workers in the oil and gas industries face the danger of fire and explosion due to ignition of flammable vapors or gases. Flammable gases, such as well gases, vapors, and hydrogen sulfide, can be released from wells, trucks, production equipment or surface equipment such as tanks and shale shakers. Ignition sources can include static, electrical energy sources, open flames, lightning, cigarettes, cutting and welding tools, hot surfaces, and frictional heat. The following OSHA and NIOSH documents provide guidance on recognizing and controlling these dangers:

- Prevention of Fatalities from Ignition of Vapors by Mobile Engines and Auxiliary Motors. OSHA and National STEPS Network and NIOSH Alliance, (June 2017). A hazard alert on how to avert fires and explosions caused by ignition of vapors by motorized equipment during drilling, servicing, and production operations.
- Well Site Ignition Sources. OSHA's Oil and Gas Drilling and servicing eTool. Lists sources of ignition at well sites and possible controls.
- Hot Work, Fire, and Explosive Hazards. OSHA's Oil and Gas Drilling and servicing eTool. Covers dangers associated with performing hot work at oil and gas well sites.
- Potential Flammability Hazard Associated with Bulk Transportation of Oilfield Exploration and Production (E&P) Waste Liquids. OSHA Safety and Health Information Bulletin, (March 24, 2008). Alerts oil and gas facilities about the flammability of oilfield waste liquids.
- Static Electricity Buildup in Plastic Pipe. OSHA Hazard Information Bulletin, (September 30, 1988). Addresses the potential for static electricity to ignite flammable gas.
- Fire Safety. OSHA Safety and Health Topics Page.
- Flammable liquids 1910.106

- Storage and handling of liquefied petroleum gases 1910.110
- Fire protection 1910 Subpart L
- Guidance on handling cases developed pursuant to the FRC enforcement policy memorandum [1910.132; 1910.132(a)], OSHA Letter of Interpretation, (December 18, 2012).
- Clarification of term "Active Hydrocarbon Zone" as it relates to the oil and gas well drilling operations; and the need to use FRC (flame-resistant clothing) when performing drilling operations [1910.132; 1910.132(a); 1910.106; 1910.119], OSHA Letter of Interpretation, (October 19, 2010). [2]

4.4. Planning and Prevention

For process-specific and task-specific dangers and controls, see OSHA's Oil and Gas Well Drilling and servicing eTool. The eTool identifies common dangers and possible solutions to diminish incidents that could lead to damages or deaths. Each drilling and servicing company should have its own protection program:

- Know the dangers. Evaluate the dangers at the worksite. Many companies within the oil and gas industry use the Job Safety Analysis Process (also referred to as a JSA, Job Hazard Analysis, or JHA) to identify risks and find solutions.
- Establish ways to protect workers, including establishing and implementing safe practices for:
  - Confined space; excavations
  - Chemical handling; exposure
  - Chemical storage
  - Electrical work
  - Emergency response
  - Equipment/machine hazards
  - Fall protection
  - Fire protection
  - Hot work, welding, flame cutting operations

4.5. Compressor Station Safety Fundamentals

As energy production continues to rise as the result of natural gas development through fracking in areas like the Marcellus and Utica shales, more infrastructures must be established in order to get materials from producers to consumers. For natural gas, this means using compressor stations to relay gas through a pipeline system. As gas travels through a pipeline it loses pressure through frictional losses with the pipe wall. In order to proficiently flow gas it is essential to boost the pressure every 40-100 miles. This task is accomplished using a compressor station, which is a facility that includes one or more compressors, usually housed inside a compressor building, with a few other attendant pieces of equipment like liquid knockout drums and associated control systems.

While these pieces of equipment are very standard and critical to supplying the energy infrastructure that our modern way of life depends on, recently there has been a substantial amount of pushback from local communities in placing this type of equipment "in their backyard". To some degree, this is logical, as those who watch the news know that there have been a significant amount of events correlated to compressor stations that have garnered unflattering attention to the industry. This is compounded by the fact that some organizations that operate compressor stations are newer to the process industries and a not as familiar with the full set of tools required to properly implement process safety as some of the more established oil and gas companies that have been doing this for over a hundred years.

The primary set of necessities for safety related to a compressor station comes from the Department of Transportation (DOT) in the Code of Federal Regulations as 49 CFR 192.163 through 49 CFR 192.173. The text of these regulations is contained in the word document found at the link shown below.

4.6. Compressor Station Regulation

You can see that the document is very short, and while it provides the key requirements that need to be attained, it does not go into a lot of detail on exactly how the requirements can be accomplished. For instance, 49 CFR 192.173 simply states: "Each compressor station building must be ventilated to guarantee that employees are not endangered by the accumulation of gas in rooms, sumps, attics, pits, or other enclosed spaces." An unsophisticated reading of this simply clause might lead one to believe that the requirement could be met by simply leaving a door open to allow the station to "air out" as required. A more sophisticated reader might have a diverse interpretation. That reader might understand that there is a great amount of potential leak locations and leak sizes that are possible, and that those leaks need to be mathematically modelled to determine the leak rates, which are a function of pressure, temperature, and composition of the gas. After determining the leak rate, one would also need to consider where the released material will go considering the size of the room, the obstructions (objects) that are in the room, and the effect of the HVAC system in moving the released gases around and out. If this type of analysis determines that pockets of gases could reach flammable concentrations, then detection and alarming of the leak along with potential automatic actions to "shut in" the compressor might also be required. That single sentence of regulation might easily be interpreted to require a highly sophisticated mathematical engineering study of potential leaks in the system along with the potential specification of engineering safeguard equipment like gas detectors. [14]

The four pages of protocols provide high level requirements, but the amount of engineering detail essential to meet those requirements is not insignificant. The best practice for the design of compressor stations with respect to technical safety should include, or at least formally consider, the following technical safety studies.

- Hazards and Operability Study (HAZOP) – to comprehend and identify danger scenarios that are possible and ensure an suitable amount of safeguards for those scenarios
- Layer of Protection Analysis (LOPA) – to acquire a deeper understanding of advanced risk scenarios and establish performance targets for safety instrumented systems for emergency shutdown

- Facility Siting Analysis – Using quantitative dispersion modeling of releases (including emergency blowdown) and explosion modeling to guarantee that the distance between the facility and neighobors is appropriate to prevent the dangerous affects of these events from harming people off the compressor station site
- Safety Instrumented System Design Basis – to develop a strategy and maintenance program that will achieve quantitative reliability targets for specified emergency shutdown systems, and also provide the appropriate documentation for design and ongoing maintenance and testing – the subsequent testing program will also be applied to other safety instrumentation including relief equipment and fire and gas detection equipment
- Fire Detector Mapping – Determining the optimal number of placement of fire detectors to detect a compressor fire and cause an appropriate response action
- Gas Detector Mapping – Model gas releases to determine if gas detection, potentially with automatic shutdown, is required, and if so, determine the appropriate number and placement of gas detectors
- Pressure Relief Design Basis – Determine the number, location, and size of required relief devices as a function of the process conditions, and equipment items utilized at the compressor station
- Cybersecurity Assessment – Design and/or audit the design of control systems (often remote supervisory control and data acquisition
- Safety Audits – Generally auditing the safety programs of compressor stations facilities that all required studies have been completed, are current, that recommendations have been followed up, and that ongoing activities are proceeding as planned.[14]

Part 5

Environmental Protection

5.1. Ecological Problem of compressor stations in Nigeria

Environmental Impacts of Compressor Stations and Natural Gas Production

Environmental impacts occur during production of crude oil and natural gas would mostly arise from long-term habitat alteration within the oil and gas field, production activities (including facilities, components maintenance or replacement), waste management (e.g produced water), noise (e.g from well operations, compressor or pump stations, flare stack, vehicle and equipment), the presence of employees and possible spills. These activities could potentially impact on the resources as explained below:[11]

5.1.1. Noise Emissions

The principal sources of noise during the production of crude oil and natural gas would comprise compressor and pumping stations, producing wells (including occasional flaring), and vehicle traffic. Compressor stations produce noise levels between 64 and 86 dBA at the station to between 58 and 75 dBA at about 1 mile (1.6 kilometers) from the station. The principal impacts from noise would be localized disturbance to wildlife, recreationists, and residents. Noise associated with cavitation is a foremost alarm for landowners, livestock, and wildlife.

5.1.2. Air Quality

The primary emission sources during the production of crude oil and natural gas would include compressor and pumping station operations, vehicle traffic, production well operations, separation of oil and gas phases, and on-site storage of crude oil. Emissions would include volatile organic compound (VOCs), nitrogen oxides, carbon monoxide, benzene, toluene, ethylbenzene, xylenes, sulfur dioxide, polycyclic aromatic hydrocarbons (PAHs), hydrogen sulfide, particulates, ozone, and methane [8]. Venting or flaring of natural gas (methane) may occur during oil production, well testing, oil and gas processing, cavitation, well leaks, and pipeline maintenance operations. Methane is a major greenhouse gas. Air pollution during oil and gas production could be detrimental to health effects and reduce visibility.

5.1.3. Cultural Resources

Production of crude oil and natural gas could also impact on the cultural resources by unauthorized collection of artifacts and the alteration of visual image. The presence of the aboveground structures alters the associated landscape factor of the cultural resources. Destruction to localities caused through off-highway vehicle (OHV) and the potential for indirect influences (e.g, vandalism and unauthorized collecting) also exist.

5.1.4. Ecological Resources

The adverse effects to ecological resources during the extraction of crude oil and natural gas could arise from: disturbance of wildlife from noise and human activity; exposure of biota to contaminants; and mortality of biota from colliding with aboveground facilities or automobiles [5]. The presence of production wells, ancillary facilities and access road reduces the habitat quality, disturbs the biota and thus upsets ecological resources. The presence of an oil or gas field could also interfere with migratory and other behaviors of some wildlife. Discharge of produced water inappropriately onto soil or into surface water bodies can result in salinity levels too high to sustain plant growth. Wildlife is always prone to contact with petroleum-based products and other contaminants in reserve pits and water management facilities [5]. They can become entrapped in the oil and drown, ingest toxic quantities of oil by preening (birds) or licking their fur (mammals); or succumb to cold stress if the oil damages the insulation provided by feathers or fur. In locations where naturally occurring radioactive material (NORM)-bearing produced water and solid wastes are generated, mismanagement of these wastes can result in radiological contamination of soils or surface water bodies.

5.1.5. Hazardous Materials and Waste Management

Industrial wastes are produced during routine operations (lubricating oils, hydraulic fluids, coolants, solvents, and cleaning agents). These wastes are typically placed in containers, characterized, labelled and possibly stored briefly before being transported by a licensed hauler to an appropriate permitted off-site disposal facility as a standard practice. Impacts could result if these wastes were not appropriately handled and were released to the environment. Environmental contamination could occur from accidental spills of herbicides or, more significantly, oil. Chemicals in open pits used to store wastes may pose a threat to wildlife and livestock. "Fracking" fluids can contain potentially toxic substances such as diesel fuel (which contains benzene, ethylbenzene, toluene, xylenes, naphthalene, and other chemicals), PAHs, methanol, formaldehyde, ethylene glycol, glycol ethers, hydrochloric acid, and sodium hydroxide [5]. Sand separated from produced water must be correctly disposed as it is frequently polluted with oil, trace amounts of metals, or other naturally occurring constituents. Production could also cause accumulation of large volumes of scale and sludge wastes inside pipelines and storage vessels [6]. These wastes may be transported to offsite disposal facilities. Produced water can become a substantial waste stream during the production of crude oil and natural gas. Regulations govern the disposal of this waste stream; the majority of it is disposed by underground injection either in disposal wells or, in mature producing fields, in enhanced oil recapture wells (i.e, wells through which produced water and other materials are injected into a producing formation in order to increase formation pressure and production). In some locations, produced water may carry NORM to the surface.[11]

5.1.6. Health and Safety

Possible influences to public health and safety during production consist of accidental injury or death to workers and, to a lesser extent, the public (e.g, from an OHV collisions with project components or vehicle collisions with oil or gas workers). Health influences could result from water contamination, dust and other air emissions, noise, soil contamination, and stress (e.g, related with living near an industrial zone). Potential fires and explosions would cause safety threats. Cavitation could ignite grass fires. Increased or reckless driving by oil or gas workers would also create safety dangers. In addition, health and safety issues include working in potential weather extremes and possible interaction with natural dangers, such as uneven terrain and dangerous plants, animals, or insects [5].

5.1.7. Land Use

Land use influences during the extraction of crude oil and natural gas would be an extension of those that occurred during the drilling/development phase. Although it is possible for farmers or fisher men to carry out activities around the well locations, boundaries would always exist.

5.1.8. Atmospheric Pollution

The Compressor Station operates on a 24-hour basis using natural gas, leading to NOx gas emission. In the area of the Station, NOx is expected to be recorded from 12 to 20 μg/m 3 and after construction it is assessed that it will reach 50 mg/m 3 before dispersion, while the limit for the safety of human health is 40 μg/m 3 NO2 and the vegetation protection limit is 30 μg/m 3 NOx.

Additional emissions are carbon monoxide (CO) while additional emissions include particulate matter (PM2.5) and volatile organic compounds (VOCs) that are currently not considered. The phenomenon of temperature inversion appears to be severe in the selected area, since it is a plain's basin enclosed by mountains. During the day, as a result of the earth heating by the sun, instability is caused in the inferior part of the atmosphere, which is in contact with the ground. As a consequence, pollutants are stuck between the earth surface and the tallest stable layer of the atmosphere. This phenomenon declines air contamination and leads to soil acidification as gaseous contaminants are deposited on the soil. Such a type of air pollution has been proven to have negative effects on people's health. More specifically, nitrogen oxides, combined with volatile organic compounds and sunlight, create smog and tropospheric ozone.

Inhalation of such smog can cause shortness of breath, wheezing and breathing difficulties. It has also been cited as a potential cause of problems, such as asthma and lung malfunction. Concerning the particulate matter PM2.5, its particles have an aerodynamic diameter of equal or less than 2.5 μm and are considered to be the most perilous, since due to their small size, they are able to reach deeper into the lungs, and may result in respiratory and cardiovascular problems [9]. 92% of the particles are respirable and PM2.5 inhalation causes various forms of pneumoconiosis, asthma, and even in some cases cancer. These negative influences affect not only humans, but also other species, such as bees. It has been proved that Nitrogen dioxide and oxides of nitrogen (NOx) affect and impair the ability of bees to detect the scent of flowers and therefore their very source of nutrition. This could lead to aggravated negative consequences for the volume of bee colonies and subsequently for the pollination of agricultural harvests. Another crucial point is that the MM5 weather model which was used for the Environmental Impacts Study is suitable for locations with an average altitude of 1.500 m., while the location in the Serres plain, where the GCS01 Compressor Station will be constructed, has a 15 m. altitude above sea level and the actual height of the Compressor aggregates emissions would be at a range between 360 and 450 m. above sea level. Moreover, the HYSPLIT pollutant dispersion model, which was used in the Environmental Impacts Study, forecasts average pollutant concentrations for long periods, but not peak concentrations in short periods of time. It has been reported that one should look at peak exposures, as compared to the averages over longer periods of time, since it appears that they are more biologically relevant if the health effect is triggered by a high, short-term dose rather than a steady dose throughout the day. Last but not least, the data provided by the National Weather Service Station in Serres, which has been in continuous operation for over 55 years, were not connected with or used by the Environmental Impacts Study. [11]

5.1.9. Accident risk

The risk for accidents is also noteworthy, since in the event of an accident-explosion in a Compressor Station, the radius of the shock wave can reach up 3.0 to 4.5 km away, within an area containing various residential settlements. Indicative is the statistic that 48% of accidents on gas pipelines are related to compressor stations and facilities, according to the Transportation Safety Board of Canada. Based on recent experience, the zone that may be affected in such an accident is quite extensive; in the 1989 explosion near the Russian city Ufa, the radius of destruction reached 4 km, according to a New York Times statement.

5.2. Methods for the Protection of the Environment

The release of these toxic compounds into the environment is principally caused by flaring, venting, improper cementing or sealing of well bore, lack of maintenance of production facilities, inefficient produced water and solid waste management scheme, poor handling of crude oil and natural gas leading to spills and leaks and non-adherence to regulations. In order to limit the release of these lethal compounds into the environment, the following approaches have been proposed:

- Commercialization of associated gas, use of new technologies, re-injection of associated gas, regulations, legislations and promotion of best practices are some of the ways used to lessen flaring and venting in crude oil and natural gas production processes.

- Proper management of well drilling and workover processes as well as integrity checks on oil and gas wells before abandonment will help check seepage of oil and gas into ground water while improved well control procedure will prevent blowouts.

- Valves and pumps are common in oil and gas production processes. Operation and maintenance plans are usually organized for the valves, pumps and other equipment to guarantee they are in good state; and not dripping out fluids.

- Produced water management facilities are usually incorporated into most production process. It could be either produced water injection system or treatment to an allowable limit before discharge into water body, in the case of offshore locations.

- Good and proficient crude oil and natural gas handling procedure is established for the production facility making sure that all protocols with respects to production of crude oil and natural gas are complied with.

5.3. Reduction of fish populations

The fishing industry is an indispensable part of Nigeria's sustainability because it offers much needed protein and nutrients for individuals, but with the higher demand on fishing, fish populations are declining as they are being depleted faster than they are able to restore their number. Fishing needs to be limited along the Niger River and aquacultures should be created to afford the rising demand on the fishing industry. Aquaculture allows for fish to be farmed for production and provide more jobs for the local people of Nigeria.

Overfishing is not the only influence on marine communities. Climate change, habitat loss, and pollution are all added pressures to these important ecosystems. The banks of the Niger River are appropriate and ideal locations for people to settle. The river provides water for drinking, bathing, cleaning, and fishing for both the dinner table and trading to make a profit. As the people have settled along the shores of the rivers and coasts, marine and terrestrial habitats are being lost and ecosystems are being drastically changed. The shoreline along the Niger River is imperative in preserving the temperature of the water because the slightest change in water temperature can be lethal to certain marine species. Trees and shrubs provide shade and habitat for marine species, while plummeting fluctuation in water temperature.

5.3.2. Natural gas flaring

Nigeria flares more natural gas associated with oil extraction than any other country, with evaluations suggesting that of the 3.5 billion cubic feet (100,000,000 m^3) of associated gas (AG) produced annually, 2.5 billion cubic feet (70,000,000 m^3), or about 70%, is wasted by flaring. This equals about 25% of the UK's total natural gas consumption and is the equivalent to 40% of Africa's gas consumption in 2001. Statistical data associated with gas flaring are notoriously unreliable, but Nigeria may waste US$2 billion per year by flaring associated gas. [11]

Flaring is done as it is expensive to separate commercially viable associated gas from the oil. Companies operating in Nigeria also harvest natural gas for commercial resolves but prefer to extract it from deposits where it is found in isolation as non-associated gas. Thus associated gas is burned off to reduce costs.

Gas flaring is largely discouraged as it releases deadly components into the atmosphere and contributes to climate change. In Western Europe 99% of associated gas is used or re-injected into the ground. Gas flaring in Nigeria arose simultaneously with oil extraction in the 1960s by Shell-BP. Alternatives to flaring are gas re-injection or to store it for use as an energy source. If appropriately stored, the gas could be used for community projects.

Gas flaring causes release of great amounts of methane, which has a high global warming potential. The methane is accompanied by the other major greenhouse gas, carbon dioxide, of which Nigeria was estimated to have emitted more than 34.38 million metric tons of in 2002, accounting for about 50% of all industrial emissions in the country and 30% of the total CO2 emissions. While flaring in the west has been minimized, in Nigeria it has continued to develop proportionally with oil production.

5.4. Conclusions

1. In view of the reliance of the world on crude oil and natural gas for energy and raw materials, the industry has continued to research on ways of optimising the production of crude oil and natural gas at very minimal cost to the environment.

2. The possibilities of failures which might lead to contamination of the environment with crude oil, natural gas, produced water, solid wastes or some other compounds used for production purposes exist.

3. Crude oil and natural gas production in most developing countries has provided immense economic benefits to both the country and the citizens. It is therefore appropriate that the government and decision makers become abreast of the full implication of the oil and gas production activities to ensure that production is sustained but in a way that is friendly to the environment and the health of the public.

COMMON CONCLUSION

1. Execute analyse of gas and oil industry in Nigeria which have important influence on Nigeria's economy.

2. The Nigeria is a big country with different climatic and geographic conditions which influence the reliability of work of different equipment.

3. Execute analyse of technological schemes of Nigeria compressor stations which displacement in different regions of country.

4. Execute analyse influence of different ambient conditions at characteristics of main compressor station equipment.

5. Considered a gas turbine driver solution to compressor stations along the Oben-Ajaokuta and Ajaokuta-Abuja-Kaduna gas pipelines taking into consideration the individual compressor station power requirement and prevailing local site conditions.

6. The effect of ambient temperature including an annual peak of 37 °C in the region was taken into account as was the altitude variation of up to 1000 m. Also, engine deterioration induced by perturbing the turbine compressor with a simultaneous 3% reduction in flow capacity and 1% reduction in efficiency was included in analysis.

7. Considered theme of defence work at object of gas transport system and improving ambient atmosphere

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