

Investigation of SO₂ and NO_x Emissions From Khoms Power Stations in Libya

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Abstract. Estimated emissions of gases from Khoms steam and gas power stations in North-Western Libya by computer simulation reveal that SO₂, NO_x emissions exceed selected international standard limits. The results highlight the need for improved operational procedures to minimize emissions, reduce equipment degradation and avoid any possible adverse environmental effects.

Keywords: SO₂, NO_x, Air Pollutants, Emissions, Simulation, Libya

1. Introduction

Emissions of SO₂ and NO_x produced from natural gas and heavy fuel oil combustion in power stations are recognized as a public health hazard and a cause of degradation of the surrounding environment. Several health problems such as respiratory disorders and allergies are attributed to such emissions [1]. Inhalation of NO_x interferes with the function of human respiratory system and worsens the health condition of asthma patients even at low concentrations [2, 3]. Increased SO₂ levels in the atmosphere are blamed for degradation of agricultural productivity and death of some plants in early stages [1, 4-7]. This study aims to calculate the concentrations of emissions from both steam and gas power stations using advanced mathematical models.

1.1. Types of industrial emissions

Stack emissions vary according to the type of industrial processes and fuel composition. There are two types of emissions, particulate and gaseous; First, gaseous emissions are products of fuel combustion that include sulfur oxides (SO₃, SO₂, SO), hydrogen sulfide (H₂S), nitrogen oxides (NO, NO₂, N₂O), carbon oxides (CO, CO₂) and volatile organic compounds (VOC's). Second, particulate matter emissions are fine dust measured in micrometres that include cement dust and carbon particles emitted from steel plants and power plants as well as different types of heavy metals [9].

1.2. Investigated emissions

Sulfur oxides are emitted from sulfur containing fuels in a form of SO₂ and SO₃. Sulfur dioxide dissolves in water vapor in the atmosphere yielding sulfite acid H₂SO₃. Sulfur trioxide is either emitted directly from the source or produced from the transformation of sulfur dioxide in the air. The occurrence of the sulfur dioxide is more common than other sulfur compounds in the lower atmosphere. Sulfur dioxide is a colorless gas with a foul odor and its presence in the surrounding air can be sensed by smelling at concentrations within 1000 to 3000 µg/m³ [1].

Nitric oxide (NO) and nitric dioxide (NO₂) are regarded as major pollutants in the lower atmosphere, in addition to nitrous oxide (N₂O) that transforms into NO and NO₂. Nitric oxide is a colorless gas with a pungent odor, varies in color from orange yellow to reddish-brown and it is a powerful oxidizing agent converts in the air into nitric acid (HNO₃).

Sources of NO_x are either natural such as volcanoes or industrial such as electric power stations, automobile engines, industrial boilers, burners, and factories producing nitrogenous compounds such as

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nitric acid. Nitrogen oxides emitted from industrial sources such as fixed industrial furnaces contribute about 30% of nitrogen oxides emissions, and 70% are attributed to power plants [1, 8].

This study is dedicated for SO₂, NO_x emitted from Khoms power stations

2. Power Station Systems

Potential pollutant emissions from gas turbines and boilers include oxides of nitrogen (NO and NO₂, collectively referred to as NO_x), carbon monoxide (CO), unburned hydrocarbons (UHC, usually expressed as equivalent methane) and oxides of sulfur (SO₂ and SO₃). Unburned hydrocarbons are made up of volatile organic compounds (VOCs). Natural gas combustion yields negligible amounts of SO₂, UHC and PMs. Thus, NO_x and CO_x constitute the most pronounced products of natural gas combustion [10].

A progressive increase in electric power production in Libya over 32 years reflects progressive increase in the demand for electricity, due to population growth and industrial expansions [11]. Energy produced from Libyan stations comes from combustion of heavy oil, light oil, and natural gas. Increasing demand for power generation is accompanied by a proportional increase in annual rates of exhaust gases such as NO_x, SO₂, CO, and CO₂ [12].

2.1. Modeling Process

Modeling is carried out by using HYSYS v3.2 to calculate mass balances of compounds involved in chemical reactions. In order to control any chemical processes and relevant changes in combustion processes, it is necessary to study the state of incoming and outgoing compound flows [13, 14]. Chemical analysis of fed fuel and excess air are essential for any simulation process in order to determine the chemical composition of emission gases. Generally, NO_x emissions are generated during fuel combustion by oxidation of chemically-bound nitrogen in the fuel and by thermal fixation of nitrogen in the combustion air. The amount of thermally generated NO_x increases as flame temperature increases. Emissions of SO₂ are generated from sulfur compounds in the fuel.

2.2. Gas Emissions Formation

There are two types of NO_x, thermal NO_x and fuel NO_x (chemical reactions are described by [9]). Combustion of oils containing significant amounts of fuel-bound nitrogen can produce up to 50% of the total NO_x emissions [15]. The most significant factors influence NO_x formation are flame temperature and the amount of nitrogen in the fuel. Other factors affecting NO_x formation are excess air level and combustion air temperature. The NO_x production rate falls sharply as either the combustion temperature decreases, or as the fuel-air ratio decreases, due to the exponential temperature effect. Therefore, an introduction of a small amount of any diluents into the combustion zone can decrease the rate of thermal NO_x production [10].

Sulfur compounds are present in liquid fuels specially Heavy Fuel Oil. As a result of combustion, sulfur in fuel evaporates in the burning zone as SO₂. A higher sulfur content can result in an increased SO₂ emission with the exit gases.

2.3. Types of Used Fuels

In recent years, natural gas has become the most favored fuel due to its lower sulfur content. The main components of natural gas are methane, ethane and other hydrocarbons. Some natural gas may also contain up to 10% inert gases such as carbon dioxide, nitrogen and helium. Sulfur presence in natural gas occurs in a form of hydrogen sulfide [9].

Heavy fuel oils (HFO) however, are still used in steam power stations. The main composition of the HFO used in Khoms steam power station is supplied by Sirte Oil & Gas Co. of Libya [16].

2.4. Combustion Reactions and Pollutants Formation

The amount of combustion gases generated from the same amount of thermal units of natural gas is 18.5% and 12.2% higher than that generated from coal and fuel oil respectively [9]. Higher volumes of

combustion gases released from natural gas combustion are attributed to air requirement. Combustion of fuel oil requires lesser amounts of air than natural gas.

The main and side reactions associated with natural gas combustion are given by Ibrahim et al.[9]. Carbon, hydrogen, nitrogen compounds and sulfur present in heavy fuel oil are fully converted into CO₂, H₂O, NO and SO₂ respectively at operating conditions.;

2.5. Simulation Process and Operating Conditions

Simulation of the combustion processes for both stations are based on the operating condition using HYSYS v3.2. Building a simulation model requires knowledge of process details and sufficient information regarding design and operation [13]. The Khoms Gas and Steam power stations operating data under steady state conditions are shown in Table.1.

The steam & gas power stations are located 7 km east of Khoms in a coastal farming strip inhabited by about 100,000 people.

Table 1. Operating data of Steam and Gas power stations [17, 18]

Data	Steam Power Station	Gas Power Station
Design efficiency	120 MW*4 units= 480 MW	150 MW*4 units= 600 MW
Operating efficiency	100 MW * 4 units= 400 MW	120 MW*4 units= 480 MW
Type of fuel	Heavy fuel oil/light fuel oil	Natural gas
Capacity of the boiler	375 Ton/hr	--
Capacity of the air compressor	--	485 Ton/hr
Operating temperature	1050 °C	1050 °C
Thermal efficiency of each unit	31.67%	34.8%
Actual excess air	15%	32%
Relative Humidity	60%	60%

3. Results and Discussion

HYSYS simulation of each station reveals that the estimated and the actual thermal efficiencies are equal. The simulation of both stations provide estimates of emission concentrations of SO₂ and NO_x. Tables (2 & 3) contain the results against the standard limits of four international codes, American (USEPA), Canadian (CEPA), European (ECE) and Saudi (KSA).

The (+) sign represents the percentage by which an emission rate of each gas exceed a certain standard limit, and the (-) sign represents the percentage by which an emission rate falls below a standard limit.

Nitrogen oxides and Sulfur dioxide emitted from the steam power station exceed all the standard limits set by the USEPA, CEPA, ECE and KSA several times corresponding to standard deviations ranging from 261% (ECE) to 6,361% (CEPA) for NO_x and from 50% (ECE) to 43,675% (CEPA) for SO₂.

Table 2. Comparison of (NO_x and SO₂) emissions from Steam Power Station with four international standard limits [18-22]

Pollutants	Standards	USEPA	CEPA	ECE	KSA
NO _x	Unit	lb/MW.hr	g/GJ	mg/m ³ (E.G.)*	lb/MBtu
	Standard limit	1.3	50	200	0.3
	Estimated value	2.56	3,230.414	722.265	7.51
	Deviation %	+1,869	+6,361	+261	+2,403
SO ₂	Unit	lb/MW.hr	kg/MW.hr	mg/m ³ (E.G.)*	lb/MBtu
	Standard limit	0.9	4.6	300	2.3
	Estimated value	16	2,013.64	450.2106	4.679
	Deviation %	+1,678	+43,675	+50	+103

* E.G. : Emitted Gases

Nitrogen oxides emitted from the gas power station follow a pattern similar to NO_x emission rates from the steam power station exceeding all the standard limits by differences correspond to standard deviations

within 1,867% (ECE) to 34,995% (CEPA) for NO_x, where SO₂ emissions are negligible as natural gas contains only traces of H₂S.

Table 3. Comparison of (NO_x and SO₂) emissions of Gas Power Station with four international standard limits [18-22]

Pollutants	Standards	USEPA	CEPA	ECE	KSA
NO _x	Unit	lb/MW.hr	g/GJ	mg/m ³ (E.G.)*	lb/MBtu
	Standard limit	1.3	40	150	0.3
	Estimated value	111	14,038.1	2,950	32.6233
	Deviation %	+8,438	+34,995	+1,867	+10,774

* E.G. : *Emitted Gases*

The excessive NO_x and SO₂ emission from both stations under steady state conditions reveal that combustion in both stations is achieved under poor operating conditions of large amounts air input exceeding the optimum amounts of excess air (10%) [15].

A comparison of results Tables (2 & 3) indicate that, the amount of NO_x emitted from the gas station is about 4 times greater than that emitted from the steam station.

Under stable meteorological condition, high concentration of SO₂ and NO_x emissions can be serious occupational health hazards. Short-term exposures (e.g., less than three hours) to low level of NO₂ may decrease lung function in individuals with preexisting respiratory illnesses. Long-term exposures well above ambient NO₂ levels may cause irreversible changes in lung structure [23]. NO_x reacts with ammonia and water droplets in the atmosphere to form nitric acid and other chemicals that are harmful to human health. Inhalation of such particles can interfere with respiratory processes and damage lung tissues. Particles inhaled deeply into the lungs can cause or aggravate respiratory conditions such as bronchitis and emphysema. Sensitive groups such as asthma and heart patients, children and elderly are at risk if exposed to SO₂ [24].

4. Conclusion

Excessive high rates of NO_x emitted from the gas power station cannot be attributed to chemical composition of natural gas. Emissions of NO_x from both power stations can mainly be attributed to large quantities of excess air exceeding the optimum values. Since natural gas is recognized an environmentally better than fuel oils high rates of the very high rates of NO_x can only be linked to improve operational procedures. Sulfur dioxide emissions are largely attributed to the combustion of HFO used as a fuel.

An increased demand on gas generated power as illustrated in Libya, highlight the impact of an increasing environmental issue. It can be concluded that deficient operation is to blame for the present excessive emissions and any related environmental impact.

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