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Investigation of SO_2 and NOx 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 SO_2, NOx 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: SO_2, NOx, air pollutants, emissions, simulation, Libya

1. Introduction

Emissions of SO_2 and NOx 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 NOx interferes with the function of human respiratory system and worsens the health condition of asthma patients even at low concentrations [2, 3]. Increased SO_2 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 Khoms 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 (SO_3, SO_2, SO), hydrogen sulfide (H_2S), nitrogen oxides (NO, NO_2, N_2O), carbon oxides (CO, CO_2) 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 SO_2 and SO_3. Sulfur dioxide dissolves in water vapor in the atmosphere yielding sulfite acid H_2SO_3. 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 $\mu g/m^3$ [1].

Nitric oxide (NO) and nitric dioxide (NO_2) are regarded as major pollutants in the lower atmosphere, in addition to nitrous oxide (N_2O) that transforms into NO and NO_2. Nitric oxide is a colorless gas with a

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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 (HNO_3).

Sources of NOx 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 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].

2. Power Station Systems

Potential emissions from gas turbines and boilers include oxides of nitrogen (NO and NO_2, collectively referred to as NOx), carbon monoxide (CO), unburned hydrocarbons (UHC, usually expressed as equivalent methane) and oxides of sulfur (SO_2 and SO_3). Unburned hydrocarbons are made up of volatile organic compounds (VOCs). Natural gas combustion yields negligible amounts of SO_2, UHC and PMs. Thus, NOx and COx constitute the most pronounced products of natural gas combustion [10].

A progressive increase in electric power production in Libya over a period of 32 years reflects a progressive increase in demand for electricity, due to population growth [11]. Energy produced from power stations in Libya 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 NOx, SO_2, CO, and CO_2 [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, NOx 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 NOx increases as flame temperature increases. Emissions of SO_2 are generated from sulfur compounds in the fuel.

2.1. Gas Emissions Formation

There are two types of NOx, thermal NOx and fuel NOx (chemical reactions are described by [9]). Combustion of oils containing significant amounts of fuel-bound nitrogen can produce up to 50% of the total NOx emissions [15]. The most significant factors influence NOx formation are flame temperature and the amount of nitrogen in the fuel. Other factors affecting NOx formation are excess air level and combustion air temperature. The NOx 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 NOx production [10].

Sulfur compounds are present in liquid fuels specially heavy fuel oil. As a result of combustion, sulfur in the fuel is released in the burning zone as SO_2. A higher sulfur content can result in an increased SO_2 emission with exit gases.

2.2. 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, however, are still in use in most steam power stations. The main composition of the heavy fuel oil used in Khoms steam power station is supplied by Sirte Oil & Gas Co. of Libya [16].

2.3. 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 oils require 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 CO_2, H_2O, NO and SO_2 respectively at operating conditions.

2.4. 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]. 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 200,000 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
Fuel	Heavy fuel oil/light fuel oil	Natural gas
Boiler capacity	375 Ton/hr	--
Air compressor capacity	--	485 Ton/hr
Operating temperature	1050 ºC	1050 ºC
Thermal efficiency (per 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 SO_2 and NOx. Tables (2 & 3) show the results against the standard limits of four international codes, American (USEPA), Canadian (CEPA), European (ECE) and Saudi (KSA).

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 NOx and from 50% (ECE) to 43,675% (CEPA) for SO_2.

Table 2. Comparison of (NOx and SO_2) emissions from Steam Power Station with four international standard limits [18-22]

Pollutants	Standards	USEPA	CEPA	ECE	KSA
NOx	*Unit*	*lb/MW.hr*	*g/GJ*	*mg/m³ (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/m³ (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.*
+ Sign represents the percentage by which an emission rate of each gas exceed a certain standard limit.

Nitrogen oxides emitted from the gas power station follow a pattern similar to NOx 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 NOx, where SO_2 emissions are negligible as natural gas contains only traces of H_2S.

Table 3. Comparison of (NOx and SO_2) emissions of Gas Power Station with four international standard limits [18-22]

Pollutants	Standards	USEPA	CEPA	ECE	KSA
	Unit	***lb/MW.hr***	***g/GJ***	***mg/m^3 (E.G.)****	***lb/MBtu***
NOx	***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*
+ Sign represents the percentage by which an emission rate of each gas exceed a certain standard limit.

Excessive NOx and SO_2 emission from both stations at steady state conditions reveal that combustion in both stations is achieved under inadequate 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 NOx emitted from the gas station is about 4 times greater than that emitted from the steam station.

Under stable meteorological condition, high concentration of SO_2 and NOx emissions can introduce serious occupational health hazards. Short-term exposures (e.g., less than three hours) to low level of NO_2 may decrease lung function in individuals with preexisting respiratory illnesses. Long-term exposures well above ambient NO_2 levels may cause irreversible changes in lung structure [23]. NOx reacts with ammonia and water droplets in the atmosphere to form nitric acid and other chemical compounds 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 SO_2 [24].

4. Conclusion

Excessive high rates of NOx emitted from the gas power station cannot be attributed to the chemical composition of natural gas. Emissions of NOx from both power stations can mainly be attributed to injection of large quantities of excess air exceeding the optimum values. Since natural gas is recognized as an environmentally friendly fuel in comparison to fuel oils, high rates of NOx can only be linked to inadequate operational procedures. Sulfur dioxide emissions can largely be attributed to the combustion of heavy fuel oil. Therefore, resorting to natural gas as an alternative to minimize gas emissions under inadequate operational procedures is evidently provides no environmental benefits.

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