H. M. Hassanien et al., Study of the effects of using acetic acid in condenser de-scaling on the exhaust emissions and the performance of Assiut thermal power plant, PP. 971 - 996

STUDY OF THE EFFECTS OF USING ACETIC ACID IN CONDENSER DE-SCALING ON THE EXHAUST EMISSIONS AND THE PERFORMANCE OF ASSIUT THERMAL POWER PLANT

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ABSTRACT

In the present study, an investigation of the effect of using acetic acid (CH_3COOH) in condenser de-scaling on the exhaust emissions and the performance of Assiut Thermal Power Plant. Efficient condenser operation maintains turbine efficiency; benefits consumers by reducing the amount of emissions. Condenser vacuum has a great effect on the unit efficiency to a degree that it reduces the generated load by 112 MW (35.9%) in unit one of Assiut Power Plant and to the extent that cleaning became very necessary. From environmentally point of view an organic, biodegradable, locally produced, effective and cheap de-scaling agent was the very applicable one and this meet with acetic acid. Actually, condenser cleaning leads to an improvement in the turbine efficiency and raises the maximum load generated from the unit (from 200 MW before cleaning to 290 MW after cleaning), decreases fuel consumed for MW (from 249 kg/MWh at load 200 MW to 220 kg/MWh at load 290 MW), reduces the overall fuel consumption, consequently, reduces emissions as CO, CO_2, SO_x, NO_x, ground level ozone, PM, VOC, ashes, solid deposits, haze, thermal pollution, and reduces contribution to global warming, heat island effect at Assiut city. In brief, the condenser cleaning process reduces the environmental pollution from the unit which in turn minimizes the health impact of these pollutants.

Keywords: Power plant, Condenser de-scaling, Air pollution

1. Introduction

Maintaining clean condenser is of vital importance for reliable, efficient power generation [1]. Internal condenser tubes fouling are detrimental to heat transfer; thus reduces the efficiency of steam condensing, resulting in a lower vacuum (higher pressure) and less efficient steam turbine operation. In severe cases; poor vacuum conditions in the condenser can reduce electric generating capacity by more than fifty percent [1]. Condenser tubes fouling have been found to have a significant impact on condenser performance and subsequently plant performance, its design specification define a maximum effective rate of removal of the latent heat in the exhaust vapor entering the condenser, as well as its transfer into the circulating water. It was found that, fouling is ubiquitous and generates tremendous operational [2] and economical losses [3], and results in reduced equipment efficiency while increasing energy consumption, increasing costs and even increasing plant downtime. Given the condenser backpressure, cooling

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water flow rate and inlet temperature; variation in these parameters will change vacuum and also affect the heat rate for a given load. Our main goal is to effectively remove fouling and deposits from condenser tube, providing a longer useful life cycle, improved condenser vacuum, a decrease in plant heat rate and a decrease in yearly fuel consumption; finally, plant performance is improved and emissions are reduced. The ills to which condensers are subject during normal service fall into these major categories:-

1. Fouling of the tube surfaces.
2. Tube or tube sheet fouling due to shell fish or debris.
3. Reduced or restricted cooling water flow rate.
4. Circulating water in-leakage.

Almost every condenser experiences some kind of tube or tube sheet fouling, where circulating water sources contain dissolved solids as the analysis shows, these dissolved solids can precipitate and become strongly deposited on the inner surface of the tubes, so adversely affecting the unite heat rate and/or limiting generation capacity. In fuel-oil-fired plants a decrease in heat rate is reflected in higher fuel consumption for a given load, and increases of 2% are common, which results in greater emissions from fuel oil plants. If the fouling becomes sever, it will cause the back pressure to rise to its upper limit, forcing a reduction in generated power, there are reports of up to 20 MW have been recovered, 2% improvement in heat rate and tons CO_2 emissions reductions achieved by the removal of sever accumulation of deposits [4].

2. Condenser cleaning

The most effective way to ensure that tubes achieve their full life expectancy and heat transfer efficiency is to keep them clean, every two to three years; a chemical cleaning is required [5]. Each time the tube deposits, sedimentation, biofouling and obstruction are removed, the tube surfaces are returned almost bare metal, providing the most effective heat transfer and the tube itself with a new life cycle, the protective oxide coating, quickly rebuild itself to repassivate the cleaned tube. There are three methods for cleaning;

1. On-line mechanical cleaning [5].
2. Off-line mechanical cleaning [1].
3. Chemical cleaning (acid cleaning) [6, 7, 8].

In the present study, the chemical cleaning method will be applied (i.e. method No. 3).

3. Chemical cleaning

In such method, the condenser is cleaned through the acid rinsing; it is one of the most effective and extensively used methods for removing mineral deposits in condenser tubes of thermal power stations [6]. Mineral scale can generally be removed by a chemical solvent such as hydrochloric acid and hydrofluoric acid [7, 9]. But rinsing with hydrochloric acid and hydrofluoric acid causes pitting and corrosion of brass condenser pipes [6], additionally, the work is expensive [9]. Mixture of acids such as Trilon B with limonic or maleic acid, adipic acid, phthalate anhydride, Low Molecular Acid (LMA), hydrochloric acid, or mixture of acids [6,7,8] were used, hydrochloric acid and a mixture of low molecular organic acids with the carbon number C_1-C_5 (formic, acetic, propionic, butyric, valeric acid) [8], mixture of (6N) oxalic and citric acid [9], mixture of acetic and nitric acid [10], hydrochloric acid with foaming agent and corrosion inhibitor as benzotriazole [6,7] also used. Because of the corrosion effect and raised costs of the traditional methods, the attention was aimed to found a cleaning agent with a cheap, locally produced, can be used at high concentration and temperature, does not have high corrosive effect, and the rinsing effluent waste must be easy to treat and biodegradable[11]. Generally, it was found that, chemical cleaning are steps:

1- Condenser tube treating with the inhibited acidic solution [7].
2- Condenser tube rinsing with fresh water [7].
3- Condenser tube passivation with passivating agent [7].

4. The relationship between emission reduction and efficiency improvement

Efficient condenser operation, consequently, increasing turbine efficiency; benefits consumers by reducing the amount of emissions, and this achieved by reducing the amount fuel required to generate the same amount of electricity [12]. Putman [4] determined a way to correlate this relationship by developing a benchmark or reference condenser duty, comparing the current operating conditions to the benchmark and then converting the difference in condenser duty or the heat loss to kgs of emissions, the performance of a condenser can be compared against a calibrated and stable frame of reference which changes only very slowly over time, tube fouling factors and condenser ambient heat discharges can also be quantified, the model also calculates (in M.J/hr) the excess heat discharged to the environment due to the fouling and its effect on the turbo generator. Fouling losses, from which avoidable emission can be calculated, are the difference between the condenser duty when fouled and that estimated if the condenser were to be cleaned and the two major properties associated with the emission calculation are [4]:-

1. Carbon, Sulfur and Nitrogen content of the fuel (weight).
2. Fuel heating value (HV).

5. Fossil fuel

Conventional power stations burn coal, oil or gas to produce electricity. Coal, oil and gas are called fossil fuels, which contains a certain amount of sulfur and nitrogen. If the combustion takes place using air as the oxygen source, the nitrogen can be added to the equation, to show the composition of the flue gas, the combustion equation is [13]:

$$CxHy + V_{O_2}(O_2 + 3.76N_2) \rightarrow V_{CO_2}CO_2 + V_{H_2O}H_2O + V_{N_2}N_2 + Heat \qquad (1)$$

In 2006, petroleum supplied the largest share of domestic energy demands, accounting for an average of 47% of total fossil-fuel-based energy consumption Figure (1).

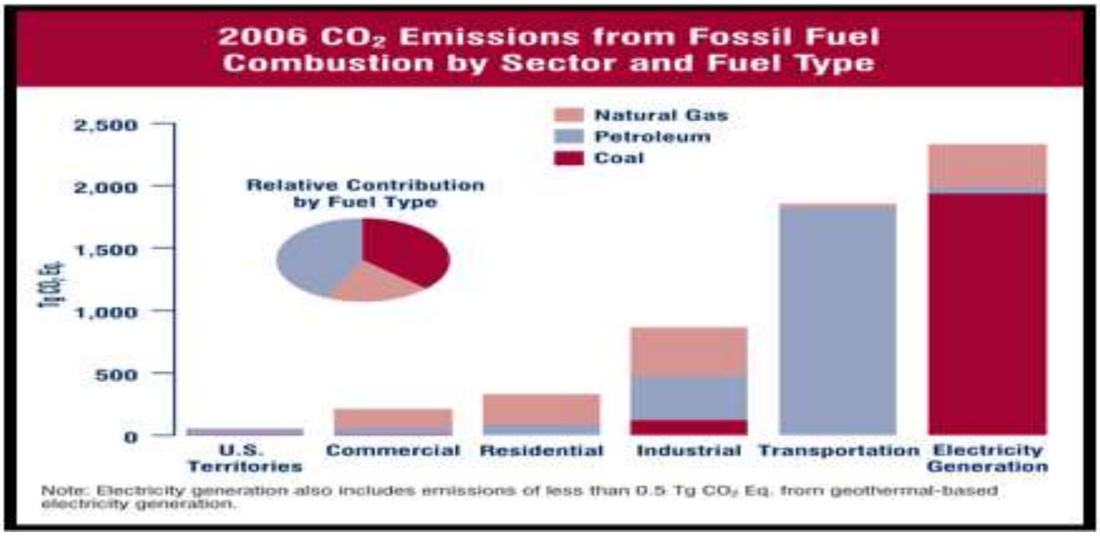

Fig. 1. source: U.S. greenhouse gas emissions inventory (y-axis units are teragrams of co$_2$ equivalent)

6. Exhaust emissions of thermal power plants

When fossil fuels are burned to produce energy the carbon stored in them is emitted almost entirely as CO_2, CO, and also releases large quantities of NO_x and SO_x, which have adversely affect on the environment, leading to the environmental pollution. Emissions may be direct or indirect, and are highly site specific depending upon the fuel being burned and the combustion system [14]. Theoretical emissions obtained from complete combustion of hydrocarbon fuels (fossil fuels) are CO_2 and H_2O; however, in practice it is impossible to have 100% complete combustion [15]. Power plants emit air pollutant directly (primary), like PM, SO_x, and NO_x, some of these pollutants can also combine with other substance in the atmosphere and form indirectly (secondary) pollutants like fine PM and ozone [16].

7. Direct emissions

7.1. Carbon dioxide (CO_2)

Combustion of fossil fuels to produce electricity and heat, contribute to the greenhouse effect caused by the formation of carbon dioxide, the greenhouse phenomenon occurs when heat radiation from earth is absorbed by the gases causing a surface temperature increase [16, 17]. Figure (2) shows specific CO_2 emissions as a function of combustion process efficiency, coal-fired (lignite and bituminous coal) electricity generation has the highest CO_2 emission rate per KWh generated whereas, heavy oil have the moderate rate and natural gas has the lowest rate, as reported [2].

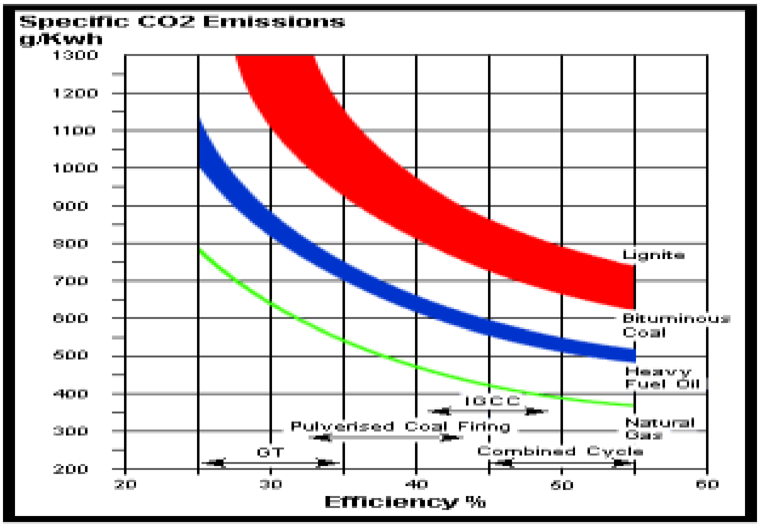

Fig. 2. Specific CO_2 emissions versus combustion efficiency

Generally the largest source of CO_2 emissions globally is the combustion of fossil fuels such as coal, oil and gas in power plants, automobiles, industrial facilities and other sources [16, 18]. The U.S. energy information agency's 1999 report on CO_2 emissions for energy generation, quotes a factor for oil power in the U.S. of 0.881 kg CO_2/kWh. Where, 1 g carbon produces 3.664 g CO_2, and, assuming a boiler combustion efficiency of 95%, the number of grams of CO_2 emission (CE) per one k J change in condenser loss may be calculated from the following equation [4]:

$$CE = \frac{3.6644 \times C \times 10^6}{0.95 \times HV} = \frac{0.9212 \times C \times 10^6}{HV} \quad \text{g / k j} \qquad (2)$$

To convert the losses due to fouling (k.J) to equivalent carbon dioxide emission (kg CO_2/h) the data contained in Table (1) may be used with equation (1) [4].

Table 1
Carbon dioxide emission, kg CO_2 per kJ losses [4]

Fuel	**C** (kg/kg fuel)	**HV** (kJ/kg)	**CO_2** (kg/kJ loss)	**Carbon** (kg/kJ loss)
Fuel Oil	0.863	43137.04	77.17	21.05

The last column in this table indicates the equivalent CO_2 emissions per kcal loss, stated in accordance with accepted IPCC [1995] [4]. In 2007 EPRI released its first Prism and MERGE analyses, providing a technically and economically feasible roadmap for the electricity sector as it seeks to reduce its greenhouse gas emissions over the next few decades [18].

7.2. Carbon monoxide (CO)

Carbon monoxide is a colorless, odorless gas, formed when substances containing carbon are burned with an insufficient supply of air. The combustion of fuels such as petrol, gas, coal and wood generate emissions of carbon monoxide. Motor vehicles are the main source of carbon monoxide pollution in urban areas [15, 16].

7.3. Nitrogen oxides (NOx)

Power stations contribute significantly to total emissions of NO_x. In 1999, in the UK, 24% of nitrogen oxides came from such source [16]. There are generally three primary sources of NO_x: thermal NO_x, fuel NO_x, and prompt NO_x. Although all of these are formed through combustion processes, they are differing slightly [19].

7.3.1. Thermal NO_x:

Thermal NO_x is formed at very high temperatures, usually above 1300 ºC, and is a result of the oxidation of the diatomic nitrogen found in combustion air. According to the Bozzuto, (1992) thermal NO formation involves the high-temperature reaction of oxygen and nitrogen from the combustion air. The principal reaction governing the formation of NO is the reaction of oxygen atoms formed from the dissociation of O_2, or possibly from H_2O_2 radical pool, with nitrogen molecules or atoms. Thermal NOx is the most produced form of NO_x created during combustion, It is a function of the temperature and the residence time of the nitrogen at that temperature; the higher the temperature of the flame the higher the formation of thermal NO_x[19].

7.3.2. Fuel NOx:

Fuel NO_x is formed when the nitrogen in fuels combines with the excess oxygen in the air. Fuel NO_x is a major problem in the burning of oil and coal as it can make up as much as 50% of total emissions when combusting oil and as much as 80% of total emissions when combusting coal [19].

7.3.3. Prompt NOx:

Prompt NO_x is formed in the earliest stage of combustion. Prompt NO_x is made by the reaction of atmospheric nitrogen with radicals in the air. The levels of prompt NO_x are generally very low, so it is usually only of interest for the most exacting emission targets. The two oxides of nitrogen of primary concern in air pollution are nitric oxide (NO) and nitrogen dioxide (NO_2), since they are emitted in significant quantities in the atmosphere [19]. Being heavier than air, NO_2 is readily soluble in water, forming nitric acid and either nitrous acid or nitric oxide, as indicated in the following equations [19]:

$$2NO_2 + H_2O \rightarrow HNO_3 + HNO_2 \quad \text{(Nitrous acid)}$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO \quad \text{(Nitric acid)}$$

A good absorber of energy in the ultraviolet range, NO_2 consequently plays a major role in the production of secondary air contaminants such as ozone. NO is emitted to the atmosphere in much larger quantities than NO_2, it is formed in high temperature combustion processes when atmospheric O_2 and N_2 combine according to the following reaction [19]:

$$N_2 + O_2 \rightarrow 2NO$$

Emissions of NO_x from combustion are primarily in the form of NO. According to the Zeldovich equations, NO are generated to the limit of available oxygen (about 200,000 ppm) in air at temperatures above 1300ºC. At temperatures below 760ºC, NO is either generated in much lower concentrations or not at all. Combustion NO is generated as a function of air to fuel ratio and is more pronounced when the mixture is on the fuel-lean side of the stoichiometric ratio 50 [19]. The Zeldovich equations are:

$$N_2 + O \rightarrow NO + N$$

$$N + O_2 \rightarrow NO + O$$

$$N + OH \rightarrow NO + H$$

Except for NO from soils, lightning and natural fires, NO is largely anthropogenic (i.e., generated by human activity). Biogenic sources are generally thought to account for less than 10% of total NO emissions as shown in Table (2) [19].

Table 2
Percentages of different sectors in NO emission production

Sector	Transportation	Power plants	Others
(%)	50	20	30

The hourly mean rate of discharge of nitrogen oxides, expressed as NO_x, emitted into the ambient air from a new generating unit when determined over successive 720 hour rolling average periods should not exceed the emission rate of 0.69 kg/MWh net energy output.

7.3.4. Sulfur Oxides (SOx):

High temperature combustion can convert sulfur in fuel to SO_2 and SO_3 and are common as air pollutants that produced from combustion of fossil fuel in thermal power plant [15]. Power plants account for over half of SO_x emissions [19]. In the gas phase sulfur dioxide is oxidized by reaction with the OH^- radical via an intermolecular reaction [20]:

$$SO_2 + OH \rightarrow HOSO_2$$

This is followed by:

$$HOSO_2 + O_2 \rightarrow HO_2 + SO_3$$

In the presence of water, SO_3 is converted rapidly to sulfuric acid:

$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(l)$$

The uncontrolled emission rate of sulfur dioxide from the generating unit in (kg/MWh) can be calculated using the formula:

$$CE = (A/B) \times C \times D \times (1000\ \mathrm{MJ/1GJ}) \qquad \text{kg/Mwh} \qquad (3)$$

Where; A; *is the sulfur concentration by mass in fuel expressed in the decimal form of a percentage, on a dry basis;* B; *is the higher HV of fuel in (MJ/kg);* C; *is a constant equal to 2, representing the ratio of molecular weight of* SO_2 *to molecular weight of sulfur; and* D; *is a constant equal to 10.6, representing the reference net plant heat rate in (GJ/MWh)*

7.3.5. Dioxins:

Dioxins are odorless, organic compounds that may be the by-products of burning fossil fuel. The term dioxins is commonly used to refer to both Polychlorinated dibenzo-p-dioxins (PCDDs) and Polychlorinated dibinzo-furans (PCDFs).the amount formed can vary greatly depending on the type of the fuel, the equipment in which the fuel is burned, and temperature of the combustion gas. Measurements that have been by EPRI and others lead to, the USEPA estimates that the air emissions from fossil fuel power plants account for only about 3% of all human-produce dioxin in the U.S., the studies showed that the forms of dioxin released by power plants tend to stick to airborne particles and soil, and do not have significant effect on human health [21].

7.3.6. Particulate Matter (PM)

The earth's atmosphere contains particulate matter (PM), these may be from natural source (such as wind-blown dust, pollen, or from gases emitted by trees and vegetation) or man-made source (burning fossil fuels, garbage, or crop wastes, and numerous industrial activities) [22]. Atmospheric PM is composed of many different chemical compound, it is emitted directly by power plants in the form of fly ash or ″secondary", formed when certain stack gases released from burning fossil fuel react with other substance in the atmosphere, as sulfate and nitrate particles. Organic particulate matter can either:

(1) PM emitted directly to the atmosphere (i.e. primary organic aerosol compounds), thermal power plants contributes to this type in the form of elemental carbon (EC) (black carbon, soot, or light absorbing carbon), which are the product of incomplete combustion [22]. Or;

(2) PM formed when volatile organic compounds (VOC) react in the atmosphere (secondary organic aerosol compounds). Organic PM can be formed in the atmosphere by reactions of VOC with inorganic acids emitted from thermal power plants, to form SOA compounds, generally, thermal power plants account for a negligible (< 0.5%) amount of anthropogenic VOC emission [23]. In general; particulate emissions from boiler burning a low ash content fuel depends more on the combustion efficiency.

8. Indirect emissions

8.1. Haze

Haze, refers to a reduction in visibility, and caused by microscopic particles suspended in the air, and they are naturally, as fine dust, pollen, and particles formed from the gases emitted by trees and vegetation, or from human activities, as burning of fossil fuels, incineration of wastes. Fossil-fueled power plants emit sulfur and nitrogen oxides that can transforms into sulfate and nitrate aerosol particles and contributes to haze, If the power stations have not effective pollution control equipment, ash-type particles can be significant source of haze [24].

8.2. Ground level ozone (smog)

Pollutants such as VOC, NO, and CO that produced from power stations are of extreme interest as ozone precursors [25]. Ozone is formed by a complex series of chemical reactions involving photo-chemically active VOCs and the good absorber of energy in the ultraviolet range NO_x in the presence of sunlight, in most highly developed urban areas, ambient concentrations of these precursor compounds are sufficient to produce the secondary air contaminants such as ozone [26, 27, 28].

8.3. Global Worming

Global warming is by direct warming by release hot flow gases to the atmosphere or by greenhouse gases emissions. The primary global warming pollutants are, in order, carbon dioxide gas, fossil-fuel plus bio-fuel soot particles, methane gas [29, 30, 31, 32], halocarbons, troposphere ozone, and nitrous oxide gas. Because air pollution and global worming problems are caused primarily by the exhaust from solid, liquid, and gas combustion during energy production and the use of such problems can be addressed only with large-scale changes to the energy sector [33].

8.4. Thermal pollution

Thermal pollution is the degradation of water quality by any process that changes ambient water temperature. Water is a very efficient and economical sink for heat engines and it is commonly used in electrical generating stations, generally, a common cause of thermal pollution is the use of water as a coolant by power plants and industrial manufacturers [34].The waste heat from electrical generating power plants is transferred to cooling water obtained from local water bodies such as a river, lake, or ocean. Large amounts of water are used to keep the sink temperature as low as possible to maintain a high thermal efficiency. The water is heated to approximately 10 ºC above ambient as it flows through the condensers and is discharged back into the local water bodies. The discharge water is rapidly mixed with ambient water and the average rise in temperature after mixing is less than 1ºC [34]. The ASTER false-color images were acquired over Joliet 29 Figure (3), a coal-burning power plant in Illinois. Joliet 29 can be seen in the VNIR image (top) as the bright blue-white pixels just above the large cooling pond. Like many power plants, Joliet 29 uses a cooling pond to discharge heated effluent water. In the bottom image a single ASTER Thermal Infrared band was color-coded to represent heat emitted from the surface. The progression from warmest to coolest is shown with the following colors: white, red, orange, yellow, green, blue, and black [34].

9. Health impact

Air pollution and global worming are two of the greatest threats to human and animal health [35], human re-production [36], gestational age [37], pregnancy outcomes [38,39], birth defects [40], birth weight [41,42], birth size [43], infant mortality [44], and political stability [45]. Indoor plus outdoor air pollution are the sixth-leading cause of death, causing over 2.4 million premature deaths worldwide. Air pollution also increases asthma, respiratory illness, cardiovascular disease, cancer, hospitalizations, emergency-room visits, work-days lost and school-days lost [46,47], leading to reduction in economic, and on the long run weakens the national security. Radim J. Šrám, et al, were published a Review [48] in 2005 about ″Ambient Air Pollution and Pregnancy Outcomes", and they reported that; There is evidence implicating air pollution in adverse effects on different birth outcomes. For air pollution and birth weight, the evidence is suggestive of causality, although further studies are needed. For birth defects, the evidence base so far is insufficient to draw conclusions. In terms of exposure to specific pollutants, particulates seem the most important for infant deaths. Intrauterine growth retardation (IUGR) seems linked to polycyclic aromatic hydrocarbons (PAHs), but the existing evidence does not allow precise identification of the different pollutants and the timing of exposure that can result in adverse pregnancy outcomes. The Center for Air Pollution Impact and Trend Analysis (CAPITA) at Washington University in St. Louis has shown that there are about equal amounts by weight of sulfate/sulfite, nitrate and organic particles making up 90% of Particulate Matter less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$). This was confirmed by Brigham Young University researchers. The Six Cities Study, published in the New England Journal of Medicine in 1990, has shown that illness and premature death are closely correlated with the amount of $PM_{2.5}$ in the air, therefore, there is epidemiological data indicting nitrogen oxides, sulfur oxides, and/or organic compounds as $PM_{2.5}$ aerosols [19].

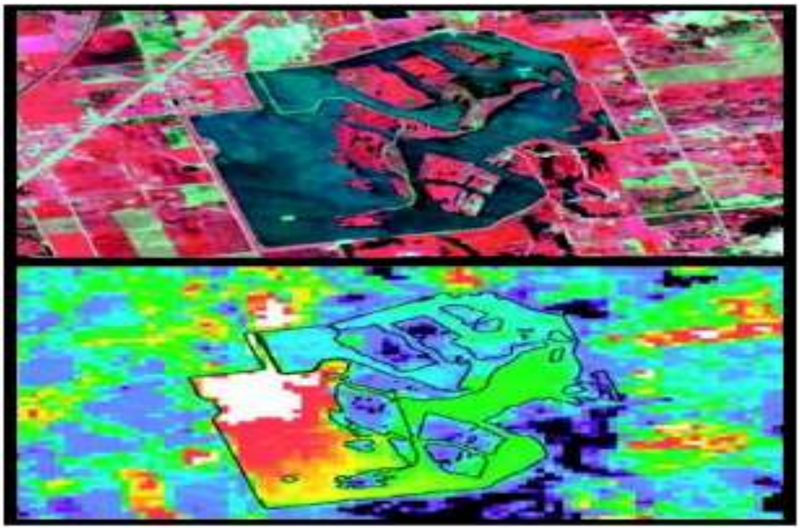

Fig. 3. Image courtesy NASA/GSFC/MITI/ERSDAC/JAROS, and U.S./Japan Aster Science Team. Reproduced by permission [34]

10. Specifications of Assiut power plant condenser

The Assiut electric power plant has two units; here we treat unit one which specifications is shown in Table (3) and Figure (4), the unit location is in Figure (5), the unit size is 312 MW and it enters the service at 5/3/1992.

Table 3

Item	**Unit 1**	
	Designed	**N. operation**
Load *MW*	312	155
Steam *ton/hr*	1024	484
Fuel cons. m^3/hr	70	35.8
No. of Burners	16	12
Steam temp. *°C*	541	540
Steam pressure *bar*	170	170
Stack height m	120m (+50m from sea level)	
Stack top width *(φ)*	φ = 5.13 m	

Fig. 4.

Fig. 5.

The condenser, cooling water and interior scales specifications are given in Table (4)

Table 4
Condenser characteristics and specifications

Tube material	90-10 (90%), 70-30 (10%) Cu-Ni alloy.
Total no. of tubes	18274(17386 tube, 90-10 Cu-Ni 888 tube, 70-30 Cu-Ni
Tube length	12.755 m
Tube inside diameter (Di)	23 mm
Tube outside diameter (Do)	24 mm
Cooling water source	Fresh water.
Circulating water flow rate	45000 ton/hr
No. of tubes bulged	100
Recommended tube cleanless factor c.f.d	0.95-1.00
Turbine back pressure (average) Ps	- 42.83 mbar.

Since the cooling water is coming from the River Nile, it contains dissolved solids, where Ca and Mg carbonates (hardiness salts) are the major constituents. These dissolved solids can precipitate and become strongly deposited on the inner surface of the condenser tubes.

Table (5) shows the analytical results of River Nile water samples through 2009 from the intake of Assiut thermal power plant. Also, a sample of the scales which precipitated and become strongly deposited on the inner surface of the condenser tubes was analyzed. Table (6) shows the analytical results of scale specimen from the inner of the study case tubes.

Table 5

Analysis results for River Nile dissolved solids (2009)

Month	Jan.	Feb.	Mar	April	May	June	July	Aug.	Sept	Oct.	Nov	Dec.
PH	8.88	8.80	8.53	8.57	8.44	8.34	8.30	8.76	8.95	8.73	8.8	8.86
Cond.(µs/cm)	343	290	310	299	292	285	290	293	308	338	317	326
Tur.(NTU)	4.10	3.40	3.20	2.25	2.47	2.50	2.31	2.77	4.10	4.41	2.8	3.75
C l (ppm)	15	14	10	10	10	8	10	10	11	12	13	13
SiO_2(ppm)	2.10	1.93	3.12	2.86	3.71	5.53	6.52	4.42	3.22	0.26	3.1	2.16
Na (ppm)	20	24	25	27	22	23	28	29	25	25	24	26
Fe (ppm)	0.17	0.12	0.10	0.17	0.16	0.15	0.14	0.11	0.28	0.14	0.1	0.2
T.Hard.ppm $CaCO_3$	122	110	118	118	110	108	111	110	110	112	114	126
Ca. H.	76	72	72	74	68	70	71	70	70	62	72	74
Mg. H.	46	38	46	44	42	38	40	40	40	50	42	52
Org. M.ppm $KMnO_4$	6.4	4.0	5.3	4.88	5.2	4.05	4.5	4.96	4.69	4.0	6.8	5.22

Table 6

Scale specimen analysis.

Element	Ca	Cu	Fe	K	Mg	Mn	Ni	Si	Ti
(%)	52.60	2.96	5.76	0.80	28.02	0.52	0.47	8.16	0.71

11. Methodology

The condenser of unit one in Assiut Thermal Power Plant consists of two sides; side A and side B each side contains about 9137 tube, during the experiment each side was divided into two sectors each one contains about 4568 tube as shown in Figure (6).

The prepared components consist of:

Stainless steel tank with 90 ton capacity, two electric pumps, steam line for heating the tank, 98 % glacial acetic acid, acid inhibitor (Benzotriazol), water jet pump, passivating agent for Cu-Ni alloy surfaces as Iron (II) Sulfate.

11.1. The cleaning procedure:-

At the beginning, the tank is rinsed, the silt and slim are removed with fresh water injection through the condenser tubes, and water boxes holes was plugged. Then;

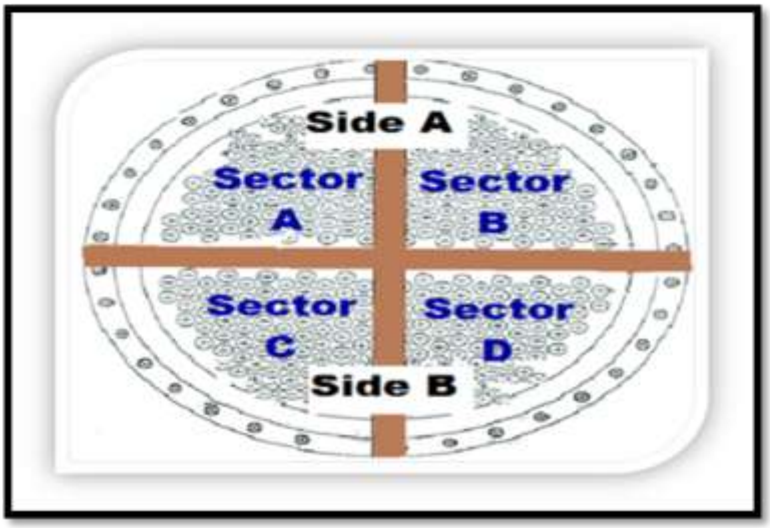

Fig. 6. Schematic of the unit condenser

11.1.1. Solution preparation:

An 80 ton of 7% acid solution was prepared in the tank by adding 5.72 ton acetic acid, 80 kg benzotriazole (about 0.1% acid inhibitor) is added, and then the tank is completed by de-mineralize water. Finally, the steam is passed through the steam heater until the solution temperature reaches 60 ^{o}C and the solution is mixed for complete homogenous.

11.1.2. Solution admitting:

The solution was admitted to the condenser sectors and circulated through the tubes to the storage tank; the circulation was continued until PH and Calcium ions concentration in the solution become constant, and then the solution we strengthen by adding acetic acid and benzotriazole, the circulation was continued until PH and Ca ions in the solution become constant again, then the solution was discharged to waste water treatment unit. The process was repeated another time (two times for each sector), and the process was continued for four days (one sector each day for about 13 hours circulation).

11.1.3. Tube flashing:

The tubes for each sector were flashed by high pressure water pumped from the jet pump until complete removal of acid and scale’s residues.

11.1.4. Condenser tube passivation:

A10 kg ferrous sulfate was added to the solution of the final rinse step for each sector, and the solution was mixed in the closed air isolated tank, then admitted to the condenser tube and stilled for 12 hr, to protect the inner tube surface by forming an oxide layer.

11.1.5. Sampling:

Sample of the solution was taken from the preparation tank, condenser tube in, condenser tube out and hot well. Then Ca, Cu, PH, acidity and temperature are determined.

11.2. Total chemicals consumed, calcium removed, cupper dissolved:-

The total acid, acid inhibitor, passivating agent, consumed removed calcium, and dissolved cupper, are in Table (7).

Table 7

Acetic Acid *ton*	**Benzotriazole** *kg*	**Passivating agent** *kg*	**Total removed Ca** *ton*	**Total removed $CaCO_3$** *ton*	**Total dissolved Cu** *kg*
64.76	682	40.00	28.432	71.080	8.7256

12. Results and discussions

From environmentally point of view, we decided to use an organic, biodegradable, locally produced, effective and cheap de-scaling agent, after studying the experimental data from the laboratory, we found that the best result, minimum copper dissolving, with negligible pitting in alloy surface, and effective; was with 7 % acetic acid solution, and 0.1% benzotriazole (as acid inhibitor) mixture and heated for 60ºC. Where acetic acid, is biodegradable as reported, and its reaction with carbonate scales is expecting to go according the following equations [11];

$$CaCO_3(s) + 2CH_3COOH(aq.) \rightarrow Ca\ (CH_3COO)_2(aq.) + CO_2(g.) + H_2O(l.)$$

$$MgCO_3(s) + 2\,CH_3COOH(aq.) \rightarrow Mg(CH_3COO)_2(aq.) + CO_2(g.) + H_2O(l.)$$

Where, the formation of CO_2 tends to drive the overall reaction by removing the product as it liberates, according to Le Chateller's principle. The acid reacts with the scales during circulating the acidic solution until its power went out, then we strengthen the mixture by adding more of the inhibited acetic acid solution and the circulation was continued until scale removal was completed, the time consumed was ranged from 12 to 13 hours and the metallurgical and microscopically investigations indicates that the tubes returned to its original state. In the following sections, the effects of condenser cleaning on both the power plant performance (presented in terms of fuel saving) and on the exhaust emissions reduction (in terms of reducing emissions of CO_2, SO_2 and NO_2) are presented.

13. Plant performance

13.1. Efficiency improvement:

By re-obtaining the original conditions of the condenser, its efficiency in heat exchanging was increased which led to increase the heat transfer rate, vacuum in condenser as shown in Figure (7), and Table (8), and consequently turbine efficiency increases to the limit with which the load was raised from maximum load 200 MW in 2009 to 290 MW, which we could not reached since 2007 until cleaning (as presented in

Figure (8), and Table (9)). Finally, we retained 90 MWh [4] and because of the decay in boiler efficiency (become 86 %), we could not reach to the maximum load of 312 MW.

Table 8
variation of condenser vacuum with years

Year	1993	2005	2006	2007	2008	2009	2010
Condenser pressure (mm H_g)	716	716	712	704	694	659	715.48

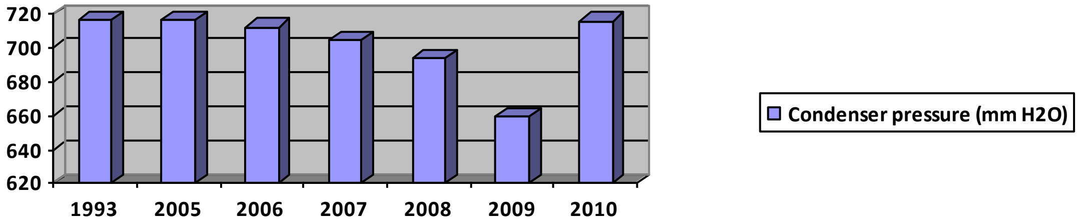

Fig. 7. variation of condenser vacuum with years

Table 9
load produced variation through the period from 2007 to 2010

Year	Load (MW)
2007	156
	200
	250
	312
2008	156
	200
	250
2009	156
	200
2010 (June)	156
	200
	250
	290

14. Fuel consumption

By increasing the turbine efficiency, the amount of fuel required to generate the same amount of electricity is reduced [12], where, tracking the amount of fuel consumed for MW through the history of Assiut Power Plant, Figure (9) and Table (10), we noticed that it increased gradually for every load with time. As an example at load 200 MW the gram fuel consumed for KWh was raised from 219.5 g in 1993 to 248.7 g in 2009.

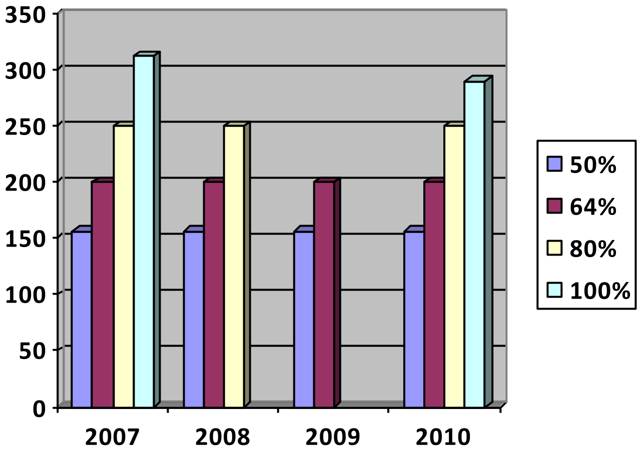

Fig. 8. Load produced variation through the period from 2007 to 2010

Table 10
the average fuel consumption before condenser cleaning under different loads in different years

Year	Load (MW)	Fuel (g/kwh)
1993	156	225
	200	219.5
	250	215.9
	312	213.6
2007	156	234.5
	200	230.5
	250	229.0
	312	230.6
2008	156	246.0
	200	242.5
	250	239.0
2009	156	252.6
	200	248.7

Figure (10) and Table (11) presents the average rates of consumed fuel in contract and before condenser cleaning in 2003, 2009 and in January 2010 at different loads.

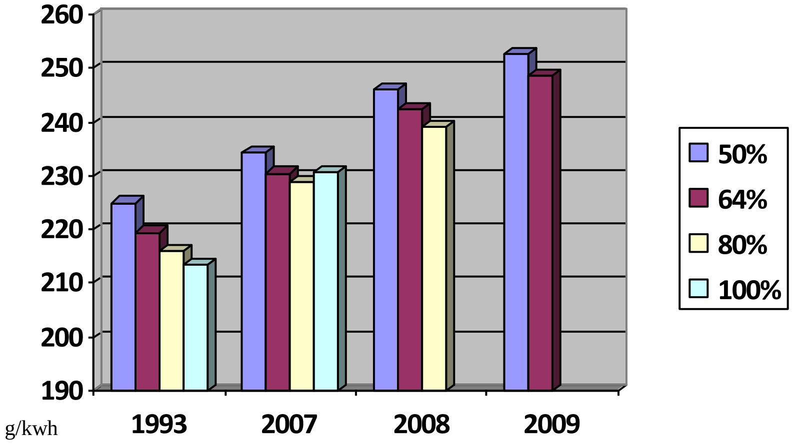

Fig. 9. the average fuel consumption before condenser cleaning under different loads in different years

Table 11
the average rates of consumed fuel g/KWh in contract and before condenser cleaning under different loads in different years

Item	156 MW (50%)	200 MW (64%)	250 MW (80%)	312 MW (100%)
Fuel consumption rate in contract (g/kWh)	223.8	215	212.6	211.6
Fuel consumption rate in 2003 (g/kWh)	233.0	223.0	218.0	217.0
Fuel consumption rate in 2009 (g/kWh)	252.6	248.7	----	----
Fuel consumption rate in January 2010 (g/kWh)	253.0	249	----	----

After condenser cleaning, the fuel consumed per KWh was considerably reduced, where; it reduced at load 200 MW from 248.7 g/KWh in 2009 to 231.5 g/KWh after cleaning in 2010, and the unit generated load raised from 200 MWh with 249 g/KWh fuel consumed to 290 MWh with 220 g/KWh as shown in, Table (12), and Figure (11) show fuel consumption at 1993 and after condenser cleaning.

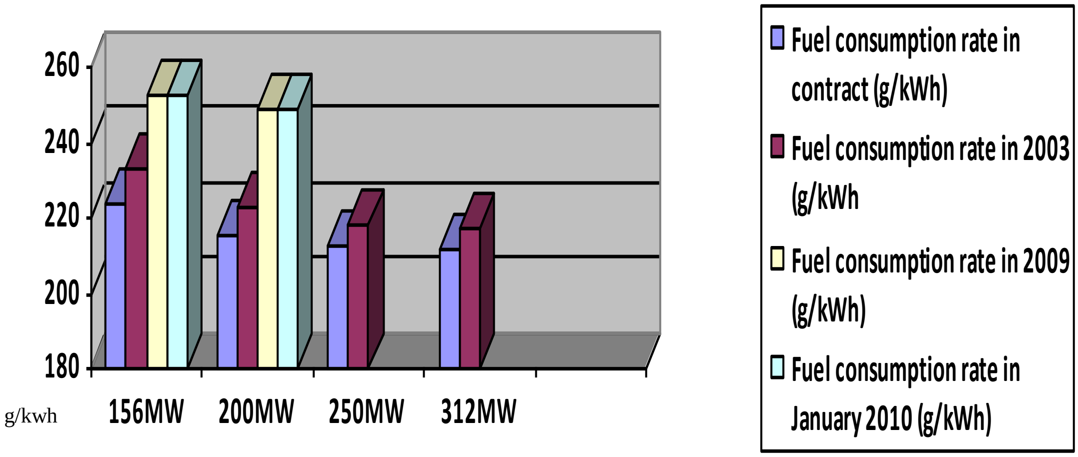

Fig.10. the average rates of consumed fuel g/KWh in contract and before condenser cleaning under different loads in different years

Table 12
the average amount of fuel consumed after condenser cleaning in June 2010

Item				
Load MW	156	200	250	290
Fuel consumption rate in 1993 g/KWh	225	219.5	215.9	213.6
Fuel consumption rate in 2010 g/KWh	234	231.5	226.0	220

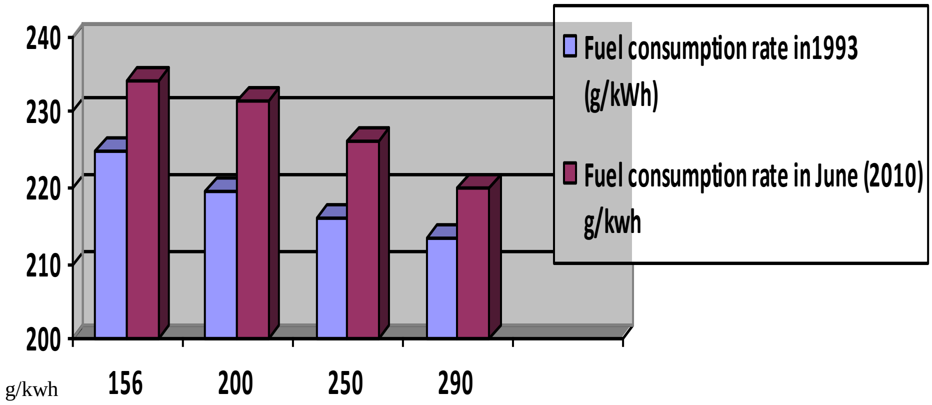

Fig.11. the average amount of fuel consumed after condenser cleaning in June 2010

Fuel consumption reduction per megawatt leads to reduction in emissions, it was reported that in Higashi-Niigata thermal power station they achieved highly efficient operation by more than 50 %, and can reduce annual fuel consumption by about 370,000 tons and CO_2 emissions by about 22 %, contributing largely to prevention of global warming. It is necessary to reduce fuel consumption at a global level in order to solve the problems concerning environment and energy; we do our best hoping to contribute to solve these problems. Table (13) presents the amount of fuel saved due to condenser cleaning of unit (1) in Assiut Power Plant, and Figure (12) shows a comparison of fuel consumption in between before and after cleaning. In that table, due to the sever need for power, the unit operates at its maximum load and thus; the saved fuel is reached to 29 kg/MWh.

Table 13
the average value of fuel saved after cleaning and at different loads

Item	156 MW	200 MW	250MW	290 MW	Remarks
Janu.2010(fuel g/kWh)	253	249	----	----	1-The load of 250 and 312 MW couldn't be reached before condenser cleaning. 2-The two values at 250 MW and 312 MW were related to maximum load (200 MW) before condenser cleaning.
June 2010fuel (g/kWh)	234.0	231.5	226.0	220	
Fuel saved (kg/MWh)	19.0	17.5	23.0	29.0	
Fuel saved ton/day	71.136	84.0	138.0	201.84	

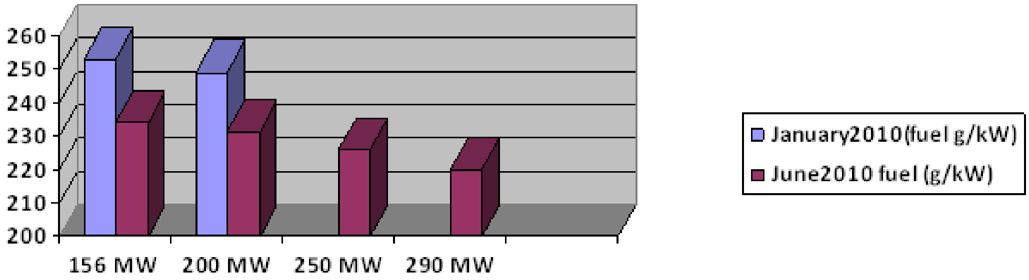

Fig.12. the average values of fuel saved after cleaning and at different loads.

15. Pollutants emissions reduction

The chemical analysis for the fuel used in Assiut Power Plant is shown in Table (14). In such table, the fuel contains 83.82 % carbon, 3.89 % Sulfur and 0.65 % Nitrogen.

Table 14
the chemical analysis of the fuel used in Assiut Power Plant

Test	Result	Method applied
Ash content (wt %)	0.069	ASTM.D-482
Asphaltnes (wt %)	2.0	IP 143
C (wt %)	83.82	ASTM.D-5373
H (wt %)	11.5	ASTM.D-5373
N (wt %)	0.65	ASTM.D-5373
Na (ppm)	24	SOLAAR S4
S (wt %)	3.89	ASTM.D-1552
V (ppm)	106.94	SOLAAR S4
Gross C.V. (j/g)	43212.1	ASTM.D-4809
Net C.V. (j/g)	40752.16	ASTM.D-4809

16. Amount of CO2 and SO2 reduced and amount of O2 saved

When the unit operates under its maximum load (290 MW), the fuel saved per day is found to be 201.84 ton/day. Since the % of carbon in the fuel is 83.82%, the amount of C burned is reduced by169.182 ton/day. Since each gram C gives 3.67 g CO_2, the amount of CO_2 emitted is reduced by 620.898 ton/day. In addition, since each gram C needs 2.67g O_2, and then the amount O_2 saved is estimated to be 451.716 ton/day. With the same manner, the amount of S burned is reduced by 7.852 ton/day and since each gram of S gives 2 g of SO_2, the reduced amount in SO_2 emission was found to be 15.704 ton/day. Table (15) together with Figure (13) present the amounts of fuel reduced, CO_2 emission reduced, SO_2 emission reduced, and the total equivalent amount of O_2 saved at the loads.

Table 15
Amounts of fuel saved, CO_2 and SO_2 emissions reduced and O_2 saved

Item	156 MW	200 MW	250 MW	290 MW	Remarks
Fuel saved ton/day	71.136	84.0	138.0	201.84	Max. load is 290 *MW*
CO_2		$C + O_2 \rightarrow CO_2$			-Carbon % in the fuel is83.82 %(*ASTMD - 5373*). -Each mol carbon gives3.67moles CO_2. -Each mol. carbon needs 2.67mole oxygen.
C ton/day	59.626	70.408	115.672	169.182	
CO_2 ton/day	218.828	258.397	424.516	620.898	
Equivalent O_2 ton/day	159.201	187.989	308.844	451.716	
SO_2		$S + O_2 \rightarrow SO_2$			-Sulfur % in the fuel is 3.89 % (*ASTM* D-*1552*). -Each mol. of S prod.2mole of SO_2. -Each mol sulfur need 2 moles of oxygen.
Sulfur ton/day	2.767	3.268	5.368	7.852	
SO_2 ton/day	5.534	6.536	10.736	15.704	
Equivalent O_2(ton/day)	2.767	3.268	5.368	7.852	
Total Equiv O_2(ton/day)	161.968	191.257	314.212	459.568	

17. Amount of NOx emissions reduced

The Nitrogen percentage in the fuel is 0.65 %, then the amount of N_2 burned is 1.312 ton/day, each gram of nitrogen needs 2.29 of O_2, the total amount of NO_2 reduced is estimated to be 4.316 ton/day. Table (16) together with Figure (14) show the variation of the amount of NO_x emissions reduced and total O_2 saved with different loads.

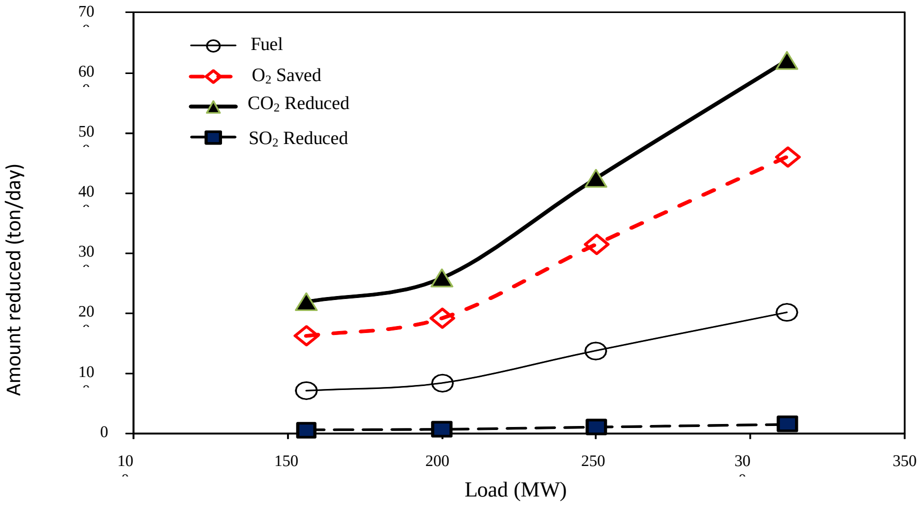

Figure 13; Amounts of fuel saved, CO_2 and SO_2 emissions reduced and O_2 saved

Table 16
amount of NO_2 emissions reduced and amount of O_2 saved.

Item	156 MW	200 MW	250 MW	290MW	Remarks
F. saved ton/day	71.136	84.0	138.0	201.84	Max. load is *290MW*
Fuel NO_2			$N + O_2 \rightarrow NO_2$		• N_2 % in the fuel is 0.65 % (*ASTM* D-*5373*). •Each mol. N_2 produces 3.29 moles of NO_2. •Each mol. N_2 needs 2 mols of O_2.
N_2 ton/day	0.462	0.546	0.897	1.312	
NO_2 ton/day	1.521	1.796	2.951	4.316	
Equ.O_2 ton/day	1.058	1.250	2.054	3.004	

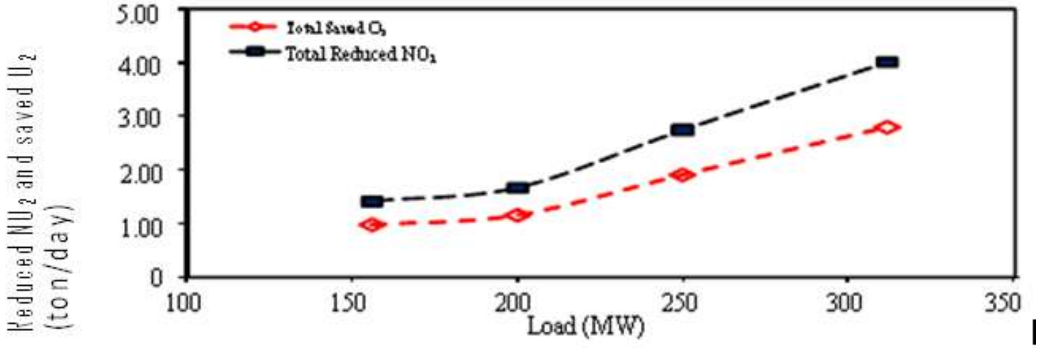

Fig. 14. amount of NO_2 emissions reduced and amount of O_2 saved.

Table (17) together with Figure (15) showing the variation of the total amounts of *CO_2*, *SO_x*, NO_2 emissions reduced and total O_2 saved with deferent load.

Table 17
Total amounts of CO_2, SO_x, and NO_x emissions reduced and total O_2 saved

Item	156 MW	200 MW	250MW	290 MW
CO_2 ton/day	218.828	258.397	424.516	620.898
SO_2 ton/day	5.534	6.536	10.736	15.704
NOx ton/day	1.521	1.796	2.951	4.316
O_2 ton/day	163.026	192.507	316.266	462.572

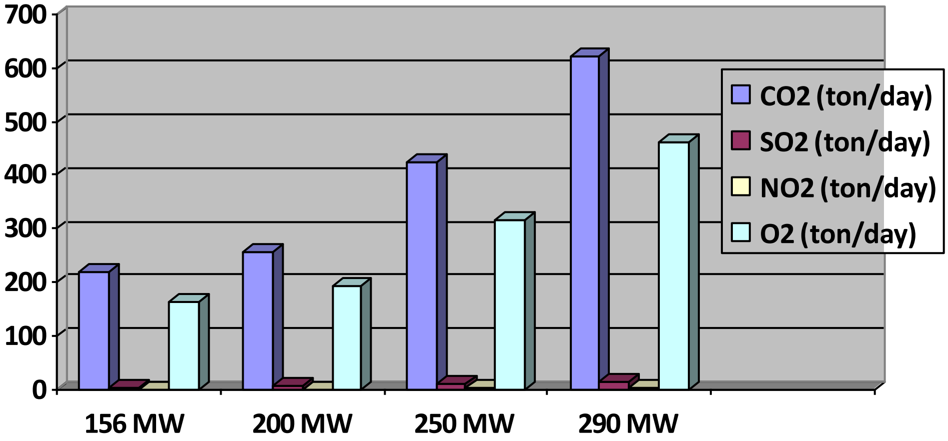

Fig. 15. total amounts of CO_2, SO_x, and NO_x emissions reduced and total O_2 saved.

18. Other pollutants

By saving this amount of fuel, the equivalent amount of CO due to incomplete combustion was eliminated, thermal pollution was reduced where, by cleaning, the total amount of cooling water was increased which led to a decrease in outlet cooling water temperature, also, the equivalent amount of PM and ozone. And reduces their contribution in global warming through the elimination of the equivalent amount of hot released gases (160ºC) the stack and the equivalent amount of ashes and solid deposits are also reduced.

19. Conclusions

In the present study, acetic acid (CH_3COOH) has been used in condenser de-scaling of Assiut Thermal Power Plant and its effects on plant performance (in terms of fuel saving) and on the exhaust emissions reduction (in terms of reducing the emissions of CO_2, SO_2 and NO_2) has been investigated. Condenser cleaning led to an improvement in the turbine efficiency and rose the maximum load generated from the unit (from 200 MW before cleaning to 290 MW after cleaning), decreased fuel consumed from 249 kg/MWh at load 200MW to 220 kg/MWh at load 290 MW, reduce the overall fuel consumption, consequently, reduced emissions as CO_2, SO_x, NO_x, CO, PM, VOC, ashes, thermal pollution, and reduced contribution to global warming, acid rain, heat island effect at Assiut city. In brief, the condenser cleaning process using CH_3COOH reduces the environmental pollution from the unit which in turn minimizes the health impact of these pollutants at Assiut city.

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الملخص:

غسيل المكثف لإزالة ما به من رواسب تعوق عملية التبادل الحراري وبالتالي عملية التكثيف التام للبخار القادم من التربينة داخل الوحدة الأولي بمحطة كهرباء أسيوط الجديدة تم بإستخدام حمض الخليك وهو حمض عضوي يتحلل بيولوجيا وبالتالي لا يترك أثر سلبي علي البيئة، كما أن الغسيل أدي إلي إسترجاع كفاءة المكثف إلي حالته الأولي مما كان له بالغ الأثر الإيجابي علي إسترجاع المحطة لكفاءاتها حيث إرتفع الحمل المنتج من *200 MW* قبل الغسيل إلي *290 MW* بعد الغسيل. وأدي ذلك إلي نقص مقدار الوقود الكلي المستهلك للميجاوات المنتجة. مما كان له أثر إيجابي أيضا علي خفض الأنبعاثات الضارة مثل CO_2, SOx, NOx, CO, والجسيمات الدقيقة، المركبات العضوية الطيارة، الرماد،والتلوث الحراري. مما يساهم في خفض المساهمة في الإحترار العالمي والأمطار الحمضية و خفض أثر تكون جزيرة حرارية علي مدينة أسيوط وفي النهاية خفض التلوث البيئي والذي بدوره يخفض الضرر الصحي المتوقع و الناتج عن هذه الملوثات علي سكان مدينة أسيوط.