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INVESTIGATION OF THE EFFECTS OF CONDENSER DE-SCALING ON THE EXHAUST EMISSIONS AND THE PERFORMANCE OF THERMAL POWER PLANTS

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ABSTRACT

The performance of thermal power plants is mainly dependent on the vacuum pressure of the condenser. The de-scaling process of the condenser can be considered as the key solution to avoid the declination of power plant performance. Accordingly, the objective of the current investigation is to study the impacts of condenser de-scaling process on the performance and exhaust emissions of thermal power plants by using an environment-friendly de-scaling agent. In this study, Assiut Thermal Power Plant (ATPP) has been carefully chosen to carry out the investigation, where the maximum load achieved on 2010 was 200 MWh out of the design load 312 MWh. Results indicate that condenser de-scaling process resulted in a significant improvement of the turbine efficiency and increased the maximum load generated to be 290 MWh rather than the previous value of 200 MWh. Additionally, a major reduction in the fuel consumption is attained which leads to decrease the exhaust emissions of CO, SO_x, and NO_x. Moreover, a considerable reduction of CO_2 emissions by more than 600 ton/day is acquired, which decreases the thermal pollution and reduces the contribution to global warming.

Keywords: Power plant, Condenser de-scaling, Exhaust emissions

1. Introduction

In thermal power stations, maintaining clean condenser is of vital importance for reliable and efficient power generation. Internal condenser tubes fouling is detrimental to heat transfer process; which reduces the efficiency of steam condensing, resulting in a lower vacuum pressure and less efficient steam turbine operation. In severe cases, poor pressure conditions in the condenser can reduce electric generating capacity by more than

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50% [1]. Condenser design specifications define a maximum effective removal rate of the latent heat in the vapor that enters the condenser, as well as its transfer rate to the circulating water. It was found that fouling is ubiquitous and generates tremendous operational [2] and economic losses [3], and results in reduced efficiency while increasing fuel consumption, increasing costs and even increasing plant downtime.

During normal operation, condensers are subjected to fouling of the tube surfaces or fouling of tubes sheet due to shellfish or debris. Almost every condenser experiences some fouling, where the circulating water sources contain dissolved solids. These dissolved solids can precipitate and become strongly deposited on the inner surface of the tubes, which adversely affects the unit heat transfer rate and limits generation capacity. In fuel-oil-fired plants, a decrease in heat rate is reflected in higher fuel consumption for a given load, which results in greater emissions. If the fouling incresed and becomes sever, it will cause the back pressure to rise to its upper limit, forcing a reduction in the generated power. Thus, effective removal of fouling and deposits from condenser tube is providing a longer useful life cycle, an improved condenser vacuum, a decrease in plant heat rate and a reduction in fuel consumption. Such reduction leads to the reduction in the plant exhaust emissions. For example, in Higashi-Niigata thermal power station in Japan [4], they achieved highly efficient operation by more than 50 %, and the annual fuel consumption was reduced by about 370,000 tons and CO_2 emissions by about 22 %, as a result of condenser descaling.

The main objective of the current work is to investigate the impacts of condenser de-scaling process on the performance and exhaust emissions of thermal power plants by using an environment-friendly de-scaling agent, which is acetic acid (CH_3COOH). To carry out the investigation, Assiut Thermal Power Plant (ATPP) has been carefully chosen where the maximum load achieved on 2010 was 200 MWh out of the design load 312 MWh.

An analytical approach using Gaussian Plume Model (GPM) is considered to assess the ground-level concentrations of SO_2 in Assiut city, based on the actual operating parameters. Comparisons between the contour-line wideness of the emitted plumes before and after condenser descaling are presented.

2. Condenser descaling

The most efficient way to ensure that tubes achieve their full life expectancy and heat transfer efficiency are to keep them clean, every two to three years [5]. Currently, there are three methods for condenser cleaning which are: on-line mechanical cleaning [5], off-line mechanical cleaning [1, 6], and chemical cleaning [6, 7, 8]. In the present study, the chemical cleaning method is applied.

Chemical cleaning of condenser tubes has three steps:

- Treating with the inhibited acidic solution [6]
- Rinsing with fresh water [6]
- Passivation with passivizing agent [6, 9]

In the chemical cleaning method, the condenser is cleaned through acid rinsing. It is one of the most effective and extensively used methods for removing mineral deposits in condenser tubes of thermal power plants [7]. The mineral scale can be removed by a chemical solvent such as hydrochloric acid and hydrofluoric acid [10, 11]. Examples of these agents are; the mixture of acids such as Trilon-B with limonic, or maleic acid, or low molecular acid, or with hydrochloric acid [7, 10, 8]. However, rinsing with hydrochloric and hydrofluoric acids causes pitting and corrosion of brass condenser pipes, in addition to the relatively high cost of such cleaning method [7, 11]. Due to these difficulties, the attention was aimed at finding a cleaning agent which is; cheap, locally produced, can be used at high concentrations and temperatures, of low corrosive effect, and biodegradable [12].

3. Selection of descaling agent

An extensive experimental work was carried out in the laboratory of ATPP to select the perfect descaling agent, which satisfies the requirements mentioned above. It was found that the best result, minimum copper dissolving, with minor pitting on the alloy surface, and efficient in deposits removal; achieved with 7% acetic acid solution, and 0.1% benzotriazole (as the acid inhibitor) mixture at a temperature of 60ºC. The most important note is that; the acetic acid is biodegradable and its reaction with carbonate scales is expecting to go according to the following equations:

$$\mathrm{CaCO_3(s) + 2CH_3COOH\,(aq.) \rightarrow Ca\,(CH_3COO)_2(aq.) + CO_2(g.) + H_2O(\mathit{l}.)}$$

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

The formation of CO_2 tends to drive the overall reaction by removing the product as it liberates, according to Le Chateller's principle [13]. The acid reacts with the scales during the circulation of the acidic solution until its power went out. The mixture is then strengthened by adding more of the inhibited acetic acid solution and the circulation was continued until completion of scale removal. The needed time is ranged from 12 to 13 hours. Then, the metallurgical and microscopically investigations are carried out to indicate if the tubes returned to its original state.

4. Relationship between condenser performance improvement and emission reduction

Efficient condenser operation, increases turbine efficiency and reducing the concentrations of the emitted pollutants. This reduction is achieved by reducing the amount of fuel which is required to generate the same amount of electricity. The performance of any condenser can be compared with a calibrated and stable frame of reference which changes only very slowly over time. Saxon and Putman [10] determined a way to correlate this relationship by developing a benchmark test, comparing the actual operating conditions to the benchmark test and then converting the difference in condenser heat loss to tons of emissions. Tube fouling parameters and condenser heat transfer rate can also be quantified. The model also calculates the excess heat discharged to the atmosphere due to fouling. Fouling losses, from which avoidable emission is estimated, are the difference between the condenser heat transfer rate with fouling and that without fouling.

5. Emissions of thermal power plants

When hydrocarbon fossil fuels are burned, the carbon stored in them is emitted almost entirely as CO_2, and CO. Also, oxides of nitrogen and sulfur are produced during the combustion process. Their emissions have adverse effects on the environment. Such emissions may be direct or indirect, and are highly depending upon the fuel burned and the combustion conditions [14]. The theoretical combustion equation of a hydrocarbon fuel in air is [15]:

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

According to equation (1), the theoretical emissions produced from complete combustion of hydrocarbon fuels are CO_2 and H_2O. However, in practice, it is impossible to have 100% complete combustion, either in power plants or internal combustion engines. Therefore, some compounds are produced from the exhaust manifold due to the incomplete combustion. Power plants emit some of these air pollutants directly, like SO_x, CO, and NO_x. Such compounds are called primary pollutants since they emitted in the atmosphere in the same form as they emitted from their sources. Some of these pollutants combine with other substances in the atmosphere and form secondary pollutants, like sulfuric acid (H_2SO_4) and Ozone (O_3).

Indirect emissions include haze, ground level ozone and acid rain. Also, thermal pollution is one of the most problems of thermal power plants. It is the rise in the temperature of water associated with the discharge of hot water from the condenser.

6. Specifications of Assiut thermal power plant (ATPP)

Assiut City is a large town on the Upper side of Egypt. It lies 234 miles south of Cairo, the capital of Egypt. The ATPP is located at 27^o 12' 46" N and 31^o 9' 56" E, at distance 3.5 km from Assiut city along the western bank of the River Nile. The plant covers a total area of 4×10^5 m^2. As shown in Fig. 1, the plant has two units, where each unit size is 312 MWh. Table 1 displays the condenser specifications of such unit and cooling water characteristics.

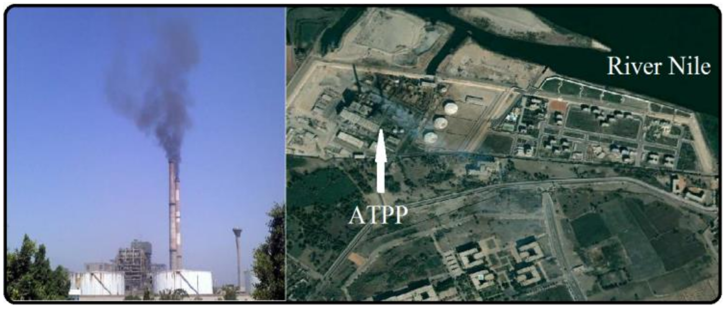


Fig. 1. A view of ATPP shows stacks of the two units and the plant location in Assiut city.

Since the cooling water comes from the River Nile, it contains dissolved solids, where Calcium and Magnesium Carbonates (hardness salts) are the major constituents. These dissolved solids can precipitate and become strongly deposited on the inner surface of the condenser tubes. Table 2 shows the analytical results of River Nile water samples. These samples were taken from the condenser intake. Additionally, a sample of the scales which precipitated on the inner surface of the condenser tubes was analyzed and presented in Table 3.

Table 1.
Condenser specifications of Unit-I of ATPP

Number of condenser tubes	18274 tubes (17386 tubes 90-10 Cu-Ni + 888 tubes 70-30 Cu-Ni)
Tube length	12.755 m
Tube inside diameter	23 mm
Tube outside diameter	24 mm
Cooling water source	Fresh water from River Nile

Number of condenser tubes	18274 tubes (17386 tubes 90-10 Cu-Ni + 888 tubes 70-30 Cu-Ni)
Circulating water flow rate	45000 ton/h
Number of tubes bulged	100
Tube cleanness factor	0.95-1.00 (recommended)
Turbine back pressure	- 42.83 mbar (average)

Table 2.
Analysis results of the River Nile dissolved solids (2010)

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**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	2.80	3.75
Cl (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	3.10	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	0.10	0.20
T. Hard. (ppm of $CaCO_3$)	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
Mn. (ppm $KMnO_4$)	6.4	4.0	5.3	4.8	5.2	4.0	4.5	4.9	4.6	4.0	6.8	5.2
T.S.S. (ppm)	25	24	26	22	20	29	21	25	18	20	16	19

Table 3.
Scale specimen analysis (2010)

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

7. Condenser cleaning procedure

The condenser of Unit-I in ATPP consists of two sides: side A and side B. Each side contains 9137 tubes. During the cleaning process, each side is divided into two sectors in such a way that; each sector contains about 4568 tubes, as shown in Fig. 2. For the condenser cleaning process, the following are prepared:

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

In the beginning, the tank is rinsed, then the silt and slim are removed using fresh water injected through the condenser tubes. The next step includes the following:

1) **Solution preparation:** An amount of 80 ton of 7% acid solution was prepared in the tank by adding 5.72 tons of acetic acid; 80 kg benzotriazole (about 0.1% acid inhibitor). Then, the tank is completed by demineralizing water. Then, the steam is passed through the steam heater until the solution temperature reaches 60 ^{o}C and the solution becomes completely homogeneous.
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. Then, the solution is strengthening by adding acetic acid and benzotriazole. The circulation is continued until PH and Calcium ions in the solution become constant again, then the solution was discharged to the wastewater treatment unit. The process is repeated for another time in each sector and continued for four days (13 hours per day).

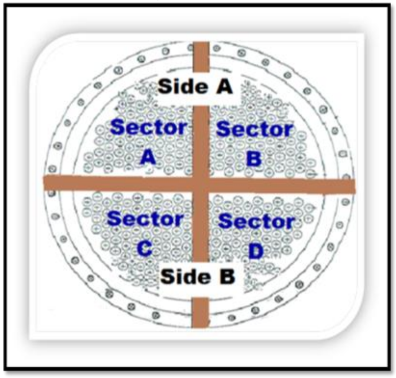


Fig. 2. A schematic of the condenser tubes of Unit I.

3) **Tube flashing:** The tubes of each sector are flashed by high-pressure water pumped from the jet pump until complete removal of acid and scale residues was attained.
4) **Condenser tube passivation:** A10 kg ferrous sulfate is added to the solution of the final rinse step for each sector, and the solution is mixed in the air isolated tank, then admitted to the condenser tube and stayed for 12 h, to avoid forming the oxide layer on the tube inner surface.
5) **Sampling:** Some samples of the solution are taken from the preparation tank, condenser tube inlet, condenser tube outlet and the hot well. Then the scales of Ca, Cu, and PH, and acidity, and temperature are measured.

8. Gaussian plume model (GPM)

To completely assess the impact of condensed descaling on the exhaust emissions in Assiut city, a mathematical model using Gaussian Plume Model (GPM) is developed. The model is developed in such a way that it calculates the wideness of the pollutant contour lines together with the values of the maximum ground-level concentration and its location with respect to the emission source.

The equation governs the concentration of a gaseous pollutant emitted from a point source is [16]:

$$c = \frac{Q}{2\pi U \sigma_y \sigma_z} * \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left\{\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right\} \quad (2)$$

where c is the pollutant concentration (g/m^3), H is the effective stack height (m), Q is the source strength (g/s), U is the wind speed at stack tip (m/s), y is the crosswind distance (m), z is the vertical distance (m), and σ_y , σ_z are horizontal and vertical dispersion parameters, respectively (m).

The effective stack height is the sum of the physical stack height h and the plume rise Δh:

$$H = h + \Delta h \tag{3}$$

The plume rise is estimated using Holland's formula [17]:

$$\Delta h = \frac{V_s D}{U}\left[1.5 + 2.68 * 10^{-3} \times p \times D \times \frac{(T_s - T_a)}{T_s}\right] \tag{4}$$

where T_s is the stack exit gas temperature (K), T_a is the atmospheric temperature (K), p is the atmospheric pressure (millibars), D is the stack exit diameter (m), V_s is the stack exit gas velocity (m/s), and z_o is the reference height (m).

The characteristics of plume dispersion depend basssically on the stability classification assigned to the scenario under investigation. The levels of atmospheric stability are classified into six stability classes based on five surface wind speed categories, three types of daytime insolation, and two types of nighttime cloudiness. These stability classes are called Pasquill-Gifford stability classes and are depicted in Table 4 [17]. Horizontal and vertical dispersion parameters σ_y and σ_z are estimated using the Briggs formulae for urban sites [18].

Table 4.
Atmospheric stability classifications (*) [17]

Surface wind speed(**) (m/s)	**Day solar insolation**			**Night cloudiness**	
	Strong	Moderate	Slight	Cloudy (≥ 4/8)	Clear (≤ 3/8)
< 2	A	A-B(***)	B	E	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

(*) A- Extremely unstable, B- Moderately unstable, C- Slightly unstable, D- Neutral, E-Slightly stable, F- Moderately stable

(**) For cases of A-B, B-C, or C-D conditions, average the values obtained for each

The power law relationship is used to estimate the wind speed at stack level:

$$U = U_o (z / z_o)^n \tag{5}$$

Values of the power-law exponent n depend on the atmospheric stability category and the terrain type [16]. Table 5 presents the values of n for the six stability categories [16].

Table 5.
Power-law exponents for the stability categories in urban areas [16]

Stability class	A	B	C	D	E	F
N	0.15	0.15	0.20	0.25	0.30	0.30

In order to estimate the SO_2 concnetration field in Assiut city, a FORTRAN-language program was developed using GPM. The calculated concentrations are estimated based on the real operating conditions of the plant and the weather conditions of Assiut city, as given in Table 6. Also, the chemical analysis of the fuel used in ATPP is shown in Table 7.

Table 6.
Operating parameter of ATPP used in GPM calculations

Sulfur percentage in the fuel	3.89 %
Stack height	120 m
Stack tip diameter	5.13 m
Stack exit temperature	150 ^oC
Incident wind direction	NE (320^o)
Ground level wind speed	4.0 m/s
Incident solar radiation	strong
Atmospheric pressure	1.0 bar
Ambient temperature	32 ^oC
Stability class	B

Table 7.
Chemical analysis of the fuel oil used in ATPP

Test	**Result**	**Method applied**
Ash content (wt %)	0.069	ASTM.D-482
Asphaltnes (wt %)	2.000	IP 143
C %	83.82	ASTM.D-5373
H %	11.50	
N (%)	0.650	
Na (ppm)	24.00	SOLAAR S4
V (ppm)	106.94	
S (%)	3.890	ASTM.D-1552
HHV (MJ/kg)	42.260	ASTM.D-4809
LHV (MJ/kg)	41.130	

9. Results and discussions

The following section presents the effects of condenser cleaning on the plant performance presented in terms of the maximum operating load achieved and the amounts of fuel saved. Also, the effect of condenser descaling on the exhaust emissions in terms of CO_2, SO_2 and NO_2 amounts at different working loads, are discussed.

9.1. Maximum operating load

By re-obtaining the original conditions of the condenser, its efficiency in heat exchanging was increased which led to increasing the heat transfer rate and condenser vacuum pressure as shown in Table 8. Thus, turbine efficiency increases to the limit, with which the load increased from 200 MWh -as the maximum load in 2009- to 290 MWh which could not be attained since 2007, as illustrated in Table 8 and Table 9. Although the condenser descaling process raises the maximum load by 90 MWh, the maximum load of 312 MWh could not be attained. This can be attributed to the decay in boiler efficiency with time, where it became 86 %.

Table 8.
History of condenser vacuum pressure against the maximum load

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010** (before cleaning)	**2010** (after cleaning)
Condenser pressure (mm H_2O)	716	712	704	694	659	259	715.5
Maximum Load (MW)	312	312	312	250	200	200	290

9.2. Fuel consumption

The greater the turbine efficiency, the lower the amount of fuel required to generate the same power. Table 9 presents the average fuel consumption before and after condenser cleaning under different working loads. The table shows that the fuel consumption rate was increased gradually from year to another. As an example; at a load of 200 MW, the fuel consumed was raised from 230.5 kg/MW.h on 2007 to 248.7 kg/MW.h on 2009.

After condenser cleaning, the fuel consumption rate was considerably reduced, where it was reduced to load 200 MW from 249.0 kg/MW.h before cleaning (January 2010) to 231.5 kg/MW.h after cleaning (June 2010). In the same time, the unit maximum generated load raised from 200 MWh with fuel consumption rate 249 kg/MW.h to 290 MW.h with the consumption rate of 220 kg/MW.h. Table 10 shows the amount of fuel consumption rates just before and after cleaning. The saved fuel amount is also calculated.

Table 9.
The average fuel consumption variation under different working loads

Year	**Load (MW)**	**Fuel consumption (kg/MW.h)**
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

Year	Load (MW)	Fuel consumption (kg/MW.h)
January 2010 (before cleaning)	156	253.0
	200	249.0
July 2010 (after cleaning)	156	234.0
	200	231.5
	250	226.0
	290	220.0

Table 10.
The average fuel consumption rate before and after condenser cleaning at different loads

Date	156 MW	200 MW	250 MW	290 MW	Remarks
January 2010 **(Before cleaning)** (kg/MW.h)	253.0	249.0	----	----	- Loads of 250 MW and 290 MW couldn't be attained before condenser cleaning. - The two values at 250 MW and 290 MW were related to the maximum load of 200 MW before condenser cleaning.
June 2010 **(After cleaning)** (kg/MW.h)	234.0	231.5	226.0	220	
Fuel saved (kg/MW.h)	19.0	17.5	23.0	29.0	
Daily fuel saved (ton/day)	71.1	84.0	138.0	201.8	

9. 3. Exhaust emissions

9.3.1. The reduced amounts of CO_2 and SO_2 emissions and the saved O_2

When the unit operates under its maximum load (290 MWh), the quantity of fuel saved per day is 201.84 ton/day. Since the percentage of carbon in the fuel is 83.82 %, the amount of carbon burned was reduced by 169.18 ton/day. Since each gram carbon gives 3.67 g CO_2, the amount of CO_2 emitted is reduced by 620.89 ton/day. Also, since 1.0 g of carbon needs 2.67 g O_2, the amount O_2 saved was 451.71 ton/day. With the same manner, the amount of sulfur burned is reduced by 7.85 ton/day. Since 1.0 g of sulfur gives 2.0 g of SO_2, the reduced amount of SO_2 emissions was 15.70 ton/day and the saved amount of O_2 was 7.8 ton/day.

9.3.2. The reduced amounts of NOx emissions and the saved O2

The nitrogen percentage in the fuel is 0.65 %. So, the amount of N_2 burned daily at a load of 290 MW is 1.31 ton. Since each gram of nitrogen needs 2.29 g of O_2 to react, the total amount of NO_2 reduced was 4.31 ton/day and the saved amount of O_2 was 3.0 ton/day.

Table 11 together with Fig. 3 present the reduced amounts of fuel, CO_2, NO_2, and SO_2 emissions at each load, and the total saved amount of O_2 at the different working loads. Additionally, Table 12 summarizes the reduced quantities of the air pollutants and the total saved O_2.

Table 11.
The reduced amounts of fuel, CO_2, SO_2 and NO_2 emissions and the saved O_2 due to condenser descaling

	156 MW	**200 MW**	**250 MW**	**290 MW**	**Remarks**
Fuel saved (ton/day)	71.1	84.0	138.0	201.8	- The maximum obtained load is 290 MWh
$C + O_2 \rightarrow CO_2$					- Fuel carbon % is 83.82. - Each gram of carbon produces 3.67 grams of CO_2. - Each g of carbon needs 2.67 grams of O_2.
C (ton/day)	59.6	70.4	115.6	169.1	
CO_2 (ton/day)	218.8	258.3	424.5	620.8	
Saved O_2 (ton/day)	159.2	187.9	308.8	451.7	
$S + O_2 \rightarrow SO_2$					- Fuel sulfur % is 3.89 %. - Each gram of S produces 2.0 grams of SO_2. - Each gram of S needs 2.0 grams of O_2.
S (ton/day)	2.7	3.2	5.3	7.8	
SO_2 (ton/day)	5.5	6.5	10.7	15.7	
Saved O_2 (ton/day)	2.7	3.2	5.3	7.8	
Fuel NO_2	$N + O_2 \rightarrow NO_2$				- Fuel nitrogen % is 0.65 %. - Each gram of N_2 produces 3.29 grams of NO_2. - Each gram of N_2 needs 2.29 grams of O_2.
N_2 (ton/day)	0.40	0.54	0.89	1.31	
NO_2 (ton/day)	1.50	1.70	2.95	4.31	
Saved O_2 (ton/day)	1.0	1.2	2.0	3.0	
Total O_2 (ton/day)	161.9	191.2	314.2	459.5	-

Table 12.
Summary of the reduced plant emissions and the saved O_2

Quantity	**156 MW**	**200 MW**	**250MW**	**290 MW**
CO_2 (ton/day)	218.82	258.39	424.51	620.89
SO_2 (ton/day)	5.53	6.53	10.73	15.70
NO_x (ton/day)	1.52	1.79	2.95	4.31
Total O_2 (ton/day)	163.02	192.50	316.26	462.57

9.3.3. Other pollutants

By saving the above-calculated quantity of fuel, the equivalent amount of CO was eliminated. The thermal pollution was also reduced since, by condenser descaling, the total amount of cooling water is increased which led to a decrease in the outlet cooling water temperature. Also, the equivalent amount of haze, PM, and ozone reduces their contribution to global warming, through the elimination of the release of hot released gasses (160ºC) into the ambient air. Finally, the equivalent quantities of ashes and solid deposits were also reduced.

9. 4. GPM results

The contour lines of SO_2 concentrations in Assiut city are presented in Fig. 4 for the load 156 MW and in Fig. 5 for the load 200 MW. The lines are advocated in the direction of the prevailing wind.

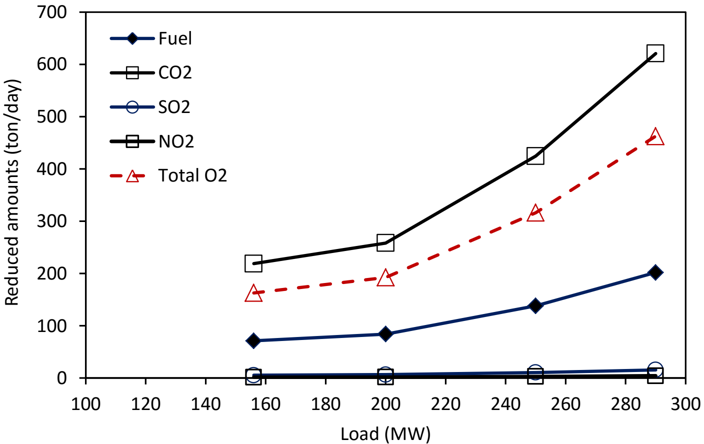
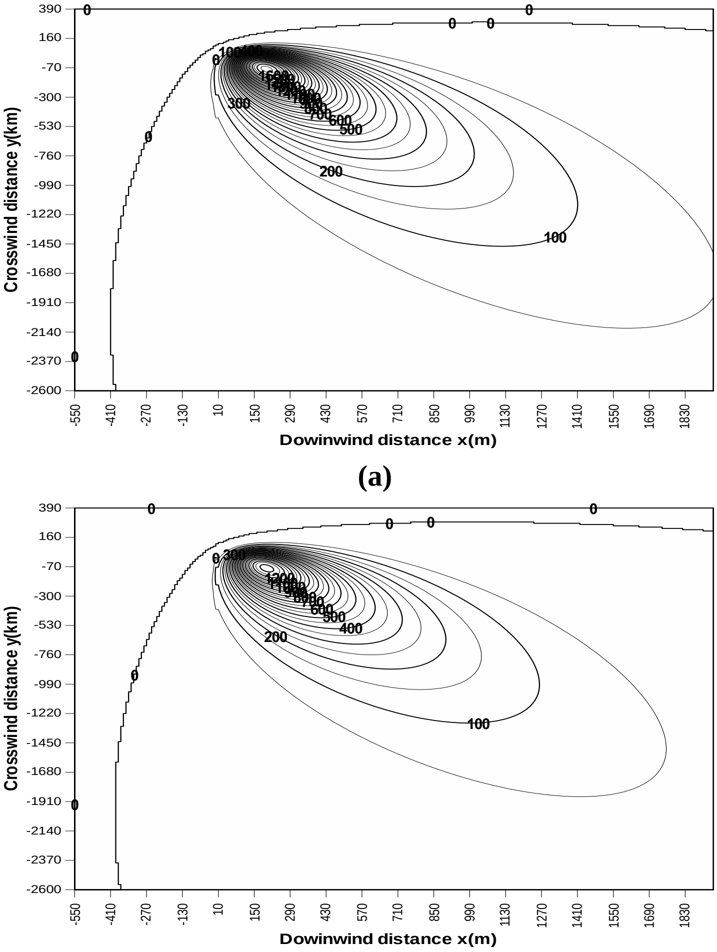


Fig. 3. The reduced amounts of fuel, CO_2, SO_2, NO_2, and the total saved O_2 due to condenser descaling



(a)

(b)

Fig. 4. The contour lines of SO_2 concentration calculated according to the conditions in Tables 6 and 7 at load 156 MW; (a) before condenser descaling, and (b) after condenser descaling.

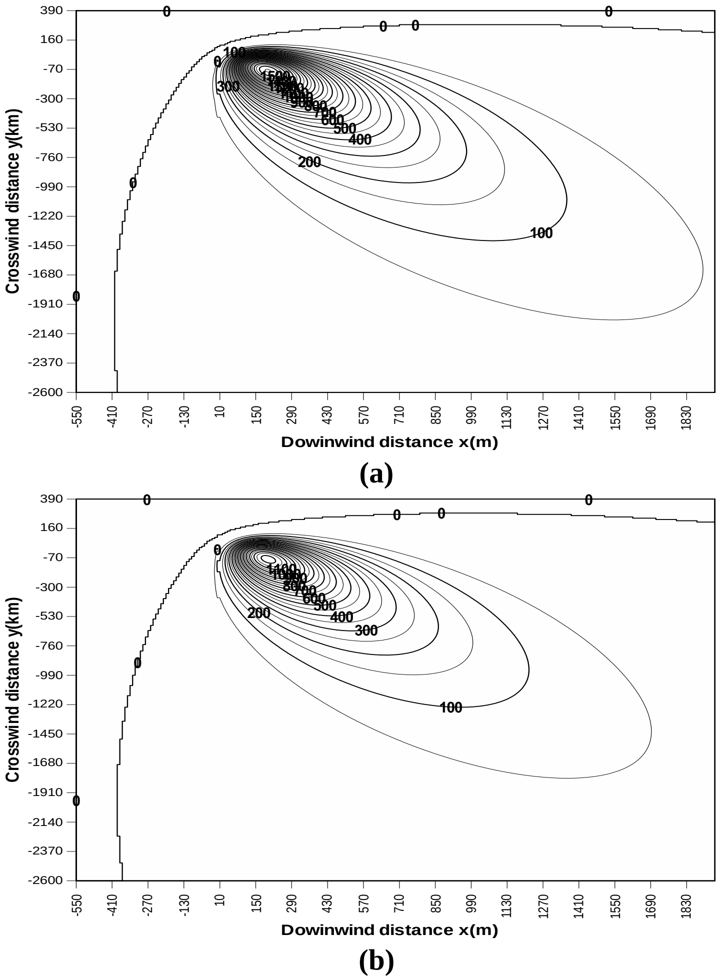


Fig. 5. The contour lines of SO_2 concentration calculated according to the conditions in Tables 6 and 7 at load 200 MW; (a) before condenser descaling, and (b) after condenser descaling.

The most important note is the plume spread within the study domain. As shown in Fig. 4(a) and 5(a), which represents the emissions of SO_2 before condenser cleaning, the contour lines of the ground-level concentrations extends to distances greater than the plume of cases 4(b) and 5(b).

The maximum ground-level concentrations of the two loads are calculated and presented in Table 13. Clearly, the maximum concentration after condenser descaling is lower than that before cleaning. Such note reflects the impact of condenser descaling on the air quality within the study domain.

Table 13.
The maximum SO_2 ground-level concentrations

C_{max} (ppm)	**156 MW**	**200 MW**
Before Cleaning	661.3	834.4
After Cleaning	611.6	775.8

To assess the impact of condenser descaling on the dispersion of SO_2 in the study domain, let us estimate the coordinates of the point along the plume centerline that have the concentration of 50 ppm in the above four cases. Table 14 shows the obtained results.

Table 14.
Coordinates of the ground-level point with 50 ppm concentrations along the plume centerline

C_{max} (ppm)	**156 MW**		**200 MW**	
	Case 4(a) (before)	Case 4(b) (after)	Case 5(a) (before)	Case 5(b) (after)
x (m)	1760	1690	1940	1880
y (m)	-1590	-1450	-1690	-1630
Distance from stack	2371.9	2226.8	2572.8	2488.2

The table shows that the distance of the 50 ppm point from the stack was decreased after condenser descaling, either with 156 MW or 200 MW loads. This result reflects that the contour lines were shrunk and its boundaries became limited compared with the contour lines boundaries before condenser descaling.

10. Conclusions

In the present study, acetic acid CH_3COOH has been cosidered as the descaling agent in the condenser of Assiut Thermal Power Plant and its effects on the plant performance, in terms of fuel saving and on the plant emissions reduction, in terms of reduced emissions of CO_2, SO_2 and NO_2 has been investigated. Analytically, Gaussian Plume Model (GPM) was used to assess the plume wideness of SO_2 emissions before and after condenser descaling to evaluate the positive impacts on the surrounding area.

Study results showed that; condenser cleaning led to an improvement in the turbine efficiency and raised the maximum load generated from 200 MWh before descaling to 290 MWh after cleaning. The fuel consumption rate was decreased from 249 kg/MW at load 200 MWh to 220 kg/MW at load 290 MWh. The reduction of the overall fuel consumption, consequently, reduced plant emissions of direct and indirect emissions. In the same time, GPM results show that; the concentration contour lines were shrined and the contour boundaries became limited, compared with the plume conditions before cleaning. In conclusions, it can be said that; condenser descaling improves power plants performance and reduces its environmental pollution, which in turn, minimizes the health impact of the plant emissions.

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دراسة تأثير إزالة ترسبات المكثف على انبعاثات العادم وألاداء في محطات توليد الطاقة الحرارية

الملخص العربى:

يعتمد أداء محطات توليد الطاقة الحرارية بالأساس على ضغط المكثف ويمكن اعتبارعملية إزالة الرواسب من علي جدران انابيب المكثف هو الحل الأمثل لتجنب انخفاض أداء محطات توليد الكهرباء. وتبعا لذلك، فإن الهدف من هذا البحث هو دراسة آثارإزالة القشور والرواسب المتراكمة علي أسطح أنابيب المكثف على الأداء وعلي انبعاثات العادم في محطات توليد الطاقة الحرارية باستخدام مادة كيميائية صديقة للبيئة. وقد تم في هذه الدراسة اختيارمحطة أسيوط الحرارية لتوليد الطاقة بعناية لإجراء البحث، حيث أن أقصى حمل يمكن الوصول اليه في عام 2010 هو 200 ميجاوات من أصل حمل التصميم المقدر ب312 ميجاوات. وتشير نتائج الدراسة إلى أن عملية غسيل المكثف من القشور والرواسب أدت إلى تحسن ملحوظ في كفاءة التوربينات وزيادة أقصى حمل الي 290 ميجاوات بدلا من القيمة السابقة 200 ميجاوات. بالإضافة إلى ذلك، تم تحقيق خفض كبير في استهلاك الوقود مما يؤدي إلى تقليل انبعاثات العادم من أكاسيد الكبريت، وأكاسيد النيتروجين وعلاوة على ذلك، حدوث خفض كبير في انبعاثات ثاني أكسيد الكربون بأكثر من 600 طن / يوم، مما يقلل التلوث الحراري ويقلل من ظاهرة الاحتباس الحراري.