Rapid Rise Of Heat Input Effects On The Tubes Characteristics In Boiler Of Steam Power Plant

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Abstract: *This work provides a theoretical and an experimental investigation of the dynamic effects of rapid rise in fuel flow rate (heat input) on the characteristics of the riser tubes in natural circulation water tube in boiler of steam power plant. In the theoretical work, the heat transfer coefficient and wall temperature are calculated and the governing equations of mathematical boiler model are solved .The experimental work was applied on the power plant of Didacta – Italia which available in Damascus University. Upper drum parameters are measured under increasing of heat input by ratio 10% and 20%.The results indicated that rapid increase in the fuel flow rate causes increased rates of evaporation and thus causes high increase in the quality that causes tube overheating. The riser temperature increases slightly above the saturation temperature due to the increase in the steam temperature and due to the dynamic influence* *resulting from sudden increase in the heat flux. The theoretical and experimental results provided good an acceptable comparison and the same behavior with Kim and Choi results and represented by graphic.*

Keywords: steam power plants, water tube boilers, and dynamic effects

Introduction

Water circulation in natural circulation drum boilers is one of the critical problems in boiler technology. Poor water circulation may cause tube rupture resulting in unscheduled boiler shutdown that may interrupt plant operation. Such poor circulation may arise from operational-type problems such as rapid rises in boiler load causing rapid rises in the heat flux as a result of rapid rises in fuel flow rates. It is known that each boiler tube experiences different heating conditions due to the no uniformity of heat flux distribution in the furnace. During the last few years, some boiler explosions were attributed to poor water circulation [1, 2].

As a result, calculations and measurements of water circulation and other operating parameters, such as steam quality and void fraction, have become more important not only for boiler manufacturers but also for large industrial establishments as well as insurance companies. Adequate water circulation is necessary to cool tubes that form boiler walls. Criteria are required to determine the potential for tube overheating. These criteria can be applied using circulation modeling and calculations to identify problem areas. Modeling the steam generator system including drum boiler, riser and down comer is one of the important problems [3, 4].

The motive force driving the steam/water mixture through the tubes in a natural circulation system is the difference in density between cooler water in the down comer circuits and the steam/water mixture in the riser tubes. This flow must be adequate to cool the tubes and prevent overheating. Normally, overheating of riser tubes are due to one of two reasons. The first occurs under steady-state conditions when the tubes are partially blocked such that the pressure losses increase.

As a result the mass flow rate of water decreases at the same heat flux causing less heat transfer to the water and consequent overheating of the tube metal. The second cause occurs when sudden rise in the heat flux occurs and is followed by an increase in the steam quality. As a result, circulation decreases as a result of increase in the pressure [5, 6].

A schematic picture of a boiler system is shown in Figure (1, a, b), the heat (Q) supplied to the riser's causes boiling. Gravity forces the saturated steam to rise causing a circulation in the riser-drum-down comer loop. Feed water is supplied to the drum and saturated steam,(q_s), is taken from the drum to the super heaters and the turbine [7].

A strom and Bell [8] developed a model of nonlinear dynamic system and describes the complicated dynamics of the physical plant. It was shown that the dynamic fuzzy model gives in some appropriate sense accurate global nonlinear prediction and at the same time that its local models are close approximations to the local linearization of the nonlinear dynamic system.

Kim and Choi [9] developed a model for water level dynamics in the drum–riser–down comer loop of a natural circulation drum-type boiler. The model is based on basic conservation rules of mass, momentum, and energy, together with the constitutional equations. The work provides an investigation of the response of water level dynamics to changes in steam demand and/or heating rate.

The present work aims to developing, utilizing nonlinear modeling, a numerical procedure for the dynamic simulation of natural circulation steam generator system and investigating the dynamic response of the pressure in the drum, steam quality at the exit of the riser tubes to rapid variations in fuel flow rate (heat input) and experimental measurement of upper drum parameters (drum pressure and drum water level) under these vibrations to optimize the steam generator operation to prevent the overheating of the riser tubes.

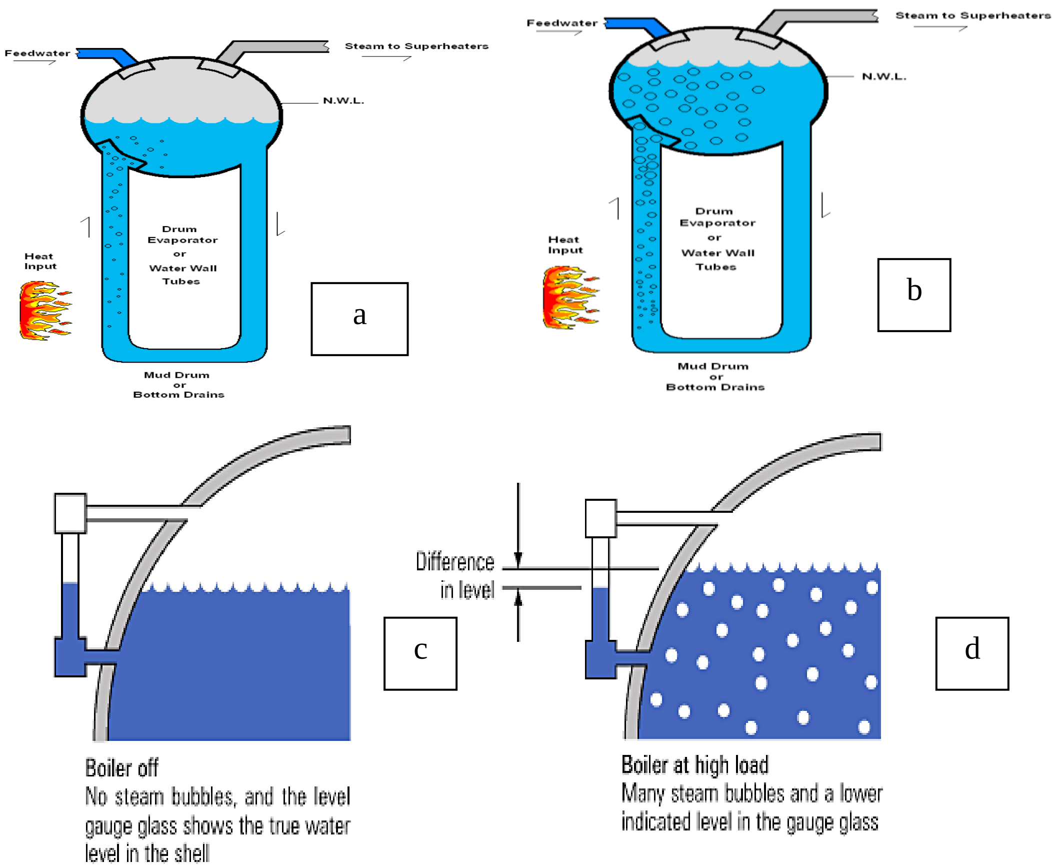

Figure (1) Bubbles effect on the drum level, a - Low firing rate, b - High firing rate, c - Neutral drum level, d - Rise drum level [7]

Theoretical Work

The theoretical work was included: - calculations of heat transfer coefficient and wall temperature, in addition of the governing equations of boiler were solved numerically.

Heat transfer coefficient calculation

The two-phase (liquid and vapor) flow pattern in a pipe depends on many parameters such as the flow velocity, the quality of the mixture, the properties of the two phases (density, viscosity and surface tension) and the pipe geometry as well as its orientation. The flow patterns in horizontal tubes are slightly different due to the effect of gravity.

A large number of empirical and semi-empirical correlations are available to predict heat transfer coefficients for the flow boiling regimes in vertical and horizontal tubes. Some of these correlations have been widely tested and are practically used. The calculation of the heat transfer coefficient includes a convection evaporation term and nucleate boiling term and is expressed as [10, 11 and 12]

$$h = h_l\left[C_l(Co)^{c_2}(25F_r)^{c_5} + BO^{c_4}F_k\right] \tag{1}$$

$$Nu = 0.023(R_{e)})^{0.8}(P_r)^{0.4} \tag{2}$$

$$F_r = \frac{G^2}{\rho^2{}_l gD} \tag{3}$$

$$BO = \frac{q}{Gh_{fg}} \tag{4}$$

$$CO = (\frac{1-x}{x})^{0.8}(\frac{\rho_v}{\rho_l})^{0.5} \tag{5}$$

Wall temperature calculations

To calculate the inside and outside wall temperatures of the riser tube [13, 14, and 15]:

$$q\pi D_o = \frac{T_i - T_{sat}}{R_{conv}} \quad , \qquad q\pi D_o = \frac{T_o - T_i}{R_{pipe}} \tag{6}$$

$$R_{pipe} = \frac{\ln(D_o / D_{in})}{2\pi K_{pipe}} \quad , \qquad R_{conv.} = \frac{1}{\pi D_i h} \tag{7}$$

The system considered includes the drum, riser and down comer, the presence of steam below the liquid level in the drum causes the shrink-and-swell phenomenon which makes level control difficult. The outflow from the risers passes through a separator to separate the steam from the water. In spite of the complexity of the system it turns out that its gross behavior is well captured by global mass and energy balances. The balance thermal equation for burning process can be obtained from the following equation: [16, 17, 18 and 19]:-

$$\frac{d\left(m_g H_{gf}\right)}{dt} = A.C_{pA}.TA + k_{comb}.B.H_{cn} - G_e C_{pg}.T_g - K_{\mathrm{Re}}(T_m{}^4 - T_S{}^4) \qquad (8)$$

Where A - Air, B - the fuel flow, Ge - the evacuated gas, Kcomb - the burning coefficient . The heat exchange to furnace zone (convection, conduction and radiation) and the water from pipes, at the saturation temperature Ts, is equivalent with a direct heat exchange through radiation. T_m is the middle temperature of burning gases.

From the low of perfect gases [20, 21 and 22]:-

$$m_g H_{gf} = \frac{V C_{vg} P_f}{R} \qquad (9)$$

$$\frac{V C_{vg}}{R} \frac{dp_f}{dt} = .C_{pA}.TA + k_{comb}.B.H_{cn} - G_e C_{pg}.T_g - K_{\mathrm{Re}}(T_m{}^4 - T_S{}^4) \qquad (10)$$

The governing equations consist of conservation of mass and energy of the total system. The equations governing the phase change in the drum include the steam and water volumes inside the drum and the rate of steam condensation and the equations governing the flow circulation in the riser– down comer loop, which govern the transport of the mass , energy and momentum .

$$a_{11}\frac{dV_{wt}}{dt}+a_{12}\frac{dP}{dt}=\dot{m}_w-\dot{m}_s \quad (11)$$

$$a_{21}\frac{dV_{wt}}{dt}+a_{22}\frac{dP}{dt}=\dot{Q}+m_w h_w-m_s h_g \quad (12)$$

$$a_{32}\frac{dP}{dt}+a_{33}\frac{dX}{dt}=\dot{Q}-xh_{fg}\dot{m}_{dc} \quad (13)$$

$$a_{42}\frac{dP}{dt}+a_{43}\frac{dX}{dt}+a_{44}\frac{dV_{sd}}{dt}=(\frac{\rho_g}{T_d})(V_{sd}{}^0-V_{sd})+\frac{(h_w-h_f)}{h_{fg}}\dot{m}_w \quad (14)$$

Thus, a set of four differentials nonlinear equations representing the time dependence of the state variables of the pressure, steam quality, total water volume and steam volume in the drum can be presented as follows [23, 24 and 25] :-

The coefficients of these four equations are given by

$$a_{11}=\rho_f-\rho_g=\rho_{fg} \quad (15)$$

$$a_{12}=V_{wt}\frac{\partial\rho_f}{\partial p}+v_{st}\frac{\partial\rho_g}{\partial p} \quad (16)$$

$$a_{21}=\rho_f h_f-\rho_g h_g \quad (17)$$

$$a_{22}=V_{wt}(h_f\frac{\partial\rho_f}{\partial p}+\rho_f\frac{\partial h_f}{\partial p})+V_{st}(h_g\frac{\partial\rho_g}{\partial p}+\rho_g\frac{\partial h_g}{\partial p})-V_t+MC_P\frac{\partial T_S}{\partial P} \quad (18)$$

$$a_{32}=(\rho_f\frac{\partial h_f}{\partial P}-Xh_{fg}\frac{\partial\rho_f}{\partial P})(1-\alpha)V_r+(1-X)h_{fg}\frac{\partial\rho_g}{\partial P}+\rho_g\frac{\partial h_g}{\partial P})\alpha V_r+$$
$$(\rho_g+X\rho_{fg})h_{fg}v_r\frac{\partial\alpha}{\partial P}-V_r+M_rC_P\frac{\partial T_S}{\partial P} \quad (19)$$

$$a_{33}=((1-X)\rho_g+X\rho_f)h_{fg}V_r\frac{\partial\alpha}{\partial x} \quad (20)$$

$$a_{42} = V_{sd}\frac{\partial \rho_g}{\partial P} + \frac{1}{h_{fg}}\{\rho_g V_{sd_s}\frac{\partial h_g}{\partial P} + \rho_f V_{wd}\frac{\partial h_f}{\partial P} - V_{sd} - V_{wd} + M_d C_P \frac{\partial T_S}{\partial P}\}$$
$$+ X(1+\beta)V_r[\alpha\frac{\partial \rho_g}{\partial P}(1-\alpha)\frac{\partial \rho_f}{\partial P} + (\rho_g - \rho_f)\frac{\partial \alpha}{\partial P}] \quad (21)$$

$$a_{43} = X(1+\beta)(\rho_g - \rho_f)V_r\frac{\partial \alpha}{\partial x} \quad (22)$$

$$a_{44} = \rho_g \quad (23)$$

The Numerical Solution

A. The initial conditions

To obtain the initial conditions, the following equations must be solving:-

$$\dot{m}_w = \dot{m}_s \quad (24)$$

$$\dot{Q} = \dot{m}_s(h_g - h_w) \quad (25)$$

$$\dot{Q} = Xh_{fg}\sqrt{\frac{2\rho_f A_{dc}(\rho_f - \rho_g)g\alpha V_r}{k}} \quad (26)$$

$$\dot{m}_r = \dot{m}_{dc} \quad (27)$$

$$\dot{m}_{ct} = \dot{m}_w(h_f - h_w)/h_{fg} \quad (28)$$

$$\alpha = \frac{\rho_f}{\rho_{fg}}[1 - \frac{\rho_s}{x\rho_{fg}}\ln(1+\frac{\rho_{fg}}{\rho_g})] \quad (29)$$

$$Q = \dot{m}_{dc}(xh_{fg}) \quad (30)$$

$$V_{sd} = V_{sd}{}^{0} - \frac{t_d(h_f - h_w)}{\rho_g h_{fg}} m_w \tag{31}$$

$$V_{wt} = V_{wd} + V_{dc} + (1-\alpha)V_r \tag{32}$$

$$t_d = \frac{\rho_g}{m_{sd}} V_{sd}{}^{0} V_{wd} + V_{dc} + (1-\alpha)V_r \tag{33}$$

B. The constants and boundary conditions

The operational data are taken from power plant characteristics such as, drum pressure, steam mass flow rate, drum volume, riser and downcomer volumes, water surface area, feed water temperature and thermal conductivity of the pipe material. There are many constants according to the boundary conditions as following [26, 27]:-

I - Convection number ≤ 0.65 (C1 = 1.136, C2 = - 0.9, C3 = 667.2, C4 = 0.7 and C5 = 0.3).

II- Convection number ≥ 0.65 (C1 = 0.6683, C2 = - 0.2, C3 =1058, C4 = 0.7 and C5 = 0.3) the convection number calculated from equation (5). C5= 0 for vertical tubes and C5 = 0 for horizontal tubes if Fr is greater than 0.04. Fk = 1 for water (a fluid dependent parameter), hL is the single phase heat transfer coefficient and is calculated from the Dittus– Boelter equation (1). $\beta = 0.3$ (Empirical value used for calculation the coefficients in equations 21 and 22).

C. The solution procedure

A numerical scheme for the solution of the governing differential equations was established. The dynamic response of the system's state variables due to rapid changes in fuel flow rate (heat input) was investigated. The present model was used for the prediction of possible tube overheating.

The solution procedure can be summarized: - equations (1)–(7) were used to calculate the heat transfer coefficient and metal temperature.

Equations (11)–(14) were solved simultaneously using an explicit method time step is 0.3 s for a total time 200 s. The coefficients in these equations were obtained from Equations (15)–(23). As well as other main boiler parameters calculated from others equations.

Experimental work

The experimental work was applied on the steam generator of Didacta – Italia power plant. All the parameters are measured after the plant reached to thermal equilibrium state and others data are taken from the technical characteristics of steam generator.

The experimental work includes the measurements and calculation of the main parameters as following:-

A. Measurements

The test was performed for the changes in drum pressure and drum water level in response to step variations in firing rate (increasing of heat input by 10%and 20%).

The measurements provide firing rate variations with time. The following parameters are measured:-

1. Measurement of drum level

The drum level has a complicated geometry d11 (glass gauge 113 mm length) as shown in figure (2) in steam generation unit. To measure the drum level response with firing rate, read drum level directly from the glass gauge (d11) with the same time when we measure the drum pressure at increasing the firing rate by (10% and 20%). The drum has a complicated geometry. The linear zed behavior can be described by the wet surface (A_d) at the operating level. The deviation of the drum level (l) measured from its normal operating level is [29]:-

$$L = \frac{V_{wd} + V_{sd}}{A_d} = L_s + L_w \qquad (34)$$

To measure the drum level response with firing rate change, read drum level directly from the glass gauge (d11) with the same time when we measure the drum pressure at increasing firing rate by (10% and 20%) . Repeat the same procedure above but in opposite i.e. drum level response with decreasing firing rate by 10 %, and 20%

2- Measurement of drum pressure

The drum pressure Gage (PI) in steam generation unit as shown in figure (2) changes with variation of firing rate (heat input), to measure this variation, we start the plant and let the plant run a long enough to reach stabilization i.e. until steam pressures and temperatures in the various points of the circuit and the cooling water temperature at outlet from the condenser remain constant. When stabilization is reached, record the drum pressure measurements with the time under increasing of firing rate by 10% and 20%. At each change, we are read the drum pressure by Gage (PI) with time.

3- Measurement of differential pressure

Δp = differential pressure (mm Hg) measured by using of a calibrated diaphragm.

4- Measurement of feed water

Feed water volume ($V_{f.w.}$) measured directly as shown in figure (2)

5- Measurement of fuel level

Fuel level measured from fuel tank as shown by figure (2)

B- Calculation procedure

The value of mass flow rate of steam (m_s) can be calculated from the following equation after measure the value of the differential pressure (Δp) mm Hg [29]:-

$$m_s = \alpha.\varepsilon \frac{\pi d^2}{4} \sqrt{2\rho \Delta p}[kg/s] \qquad (35)$$

Where, α - coefficient of discharge = 0.60845, ε - expansibility factor= 0.99658, d - orifice diameter = 20.5 mm, internal pipe diameter =27mm,

Steam temperature (T_s) measured directly from the control unit in steam power plant **(**Electric control and command board). Also the data of burner are taken from the technical characteristics of burner such as, rate of consumption (m_f) can be calculating from the following equation [29]:-

$$m_{f.} = \frac{L_f * 0.8}{\tau_{f.}} * 3600[kg/h] \qquad (36)$$

Where, L_f = level reading of fuel tank, 0.8 = specific weight of the fuel, τ_f = measured time.

Feed water mass flow rate (m_w) calculated by measured of feed water volume ($V_{f.w.}$), and time of boiler operation ($\tau_{b.p.}$), $v_{f.w.}$ was taken from tables (according to pressure and temperature of boiler), then (m_w) can be calculate from the following equation [29]:-

$$m_{w.} = \frac{\dot{V}_{f.w.}}{v_{f.w.}} \qquad (37)$$

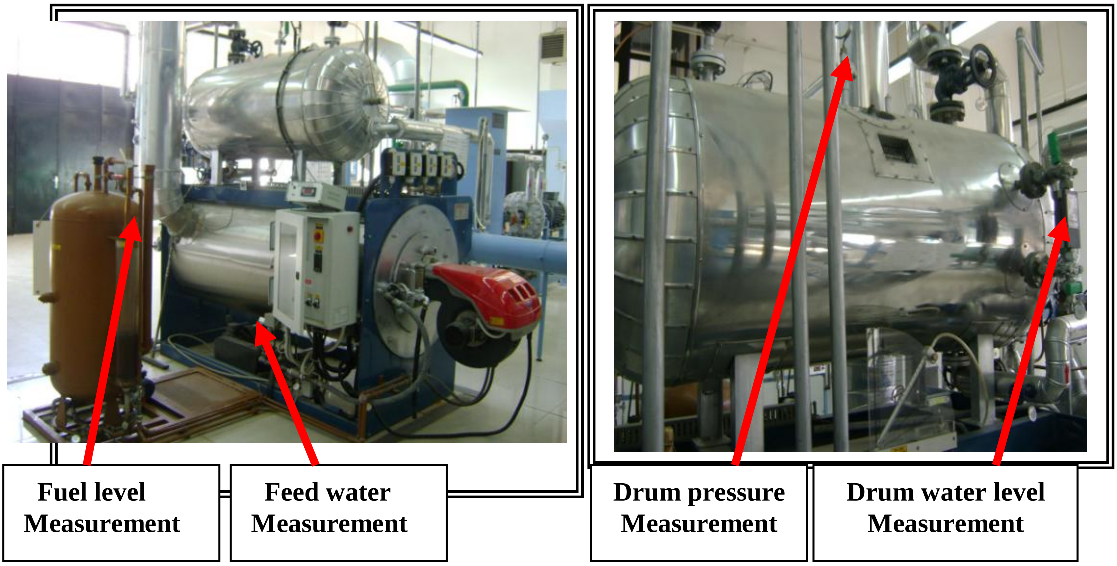

Figure (2) Steam generation unit of power plant (Didacta-Italia)

Results and discussion

Figure 3 presents an experimental and theoretical behavior of drum pressure with time; the fluctuation of drum pressure with time is due to the firing rate variations with time as shown in figure 4.

Figure 5 presents the change of the pressure as a result of sudden increase in heat input (Q), and shows that the pressure increases at a constant rate of dP/dt as a result of a step rise in the heat input of 10% and for the case of 20% step rise in the heat input in order to explain the increase in the drum pressure.

Figures (6 and 7) are provided and present the response of the mass flow rates in risers and downcomers for the two cases of step rise in heat input. The riser mass flow exhibits a sudden increase as a result of increase in the heat input. As the heat input, is increased, a sudden increase from the steady-state value in the mass flow rate in the riser occurs.

However, the downcomer flow exhibits a gradual increase with time. Thus, the outlet of the riser first increases and then decreases to match the flow in the downcomer. Thus, the difference between the riser and downcomer mass flow rates, increases suddenly causing increase in the mass flow rate into the drum and the volume of steam–water in the drum.

The difference between both of the two flow rates diminishes at around 30 s from the moment of the step rise in heat input. This is followed by a continuous gradual decrease in the risers and downcomers mass flow rates.

The case of 20% step rise shows similar trends but with higher magnitudes of flow rates in risers and downcomers. As well, the difference between the riser and downcomers at start of the rise is much higher for the case of 20%. Consistent with the increase in heat input, the quality at exit of the riser increases as a result of increased rate of evaporation. The quality increases first at a high rate during the first 10 s.

Figures (8 and 9) are present the dynamics of steam and water volumes in the drum under the water level. The difference between the mass flow rate in the risers and downcomers along with the increase in the quality leads to a rise in the mass of water as well as steam in the drum As well, as shown in Figures (8and9), the volume of the steam within the liquid (under water level) in the drum, Vsd, increases as a result of a combined increase in the riser flow rate and the quality at exit of the riser. The increase in the riser flow rate and the quality cause high increase in steam flow into the drum, which results in increase in Vsd.

Figure (10) indicates that the rate of condensation as a result of increase in pressure increases suddenly and then continues to increase but at a lower rate. The main cause of condensation is due to the increase in the pressure at the same saturation temperature Ts .

Figure (11) shows that the total volume of water in the system, Vwt, increases . The increase in Vwt is a result of increase of Vwd and the condensation of the steam under the water level in the drum. Consistent with the increase in the total water volume, Vwt, Figure 9 shows a decrease in the total steam volume, Vst, according to the relation Vst+ Vwt= V .

The response of heat transfer coefficient, h, is shown in figure (12) and the response of the liquid heat transfer coefficient; hL is presented in figure (13). As shown in Figure (12), h decreases during the first ten seconds. This is followed by increase in h with time. Despite that the case of 20% exhibit higher values of h, the rate of increase in h is slower for the case of 20%.
Figure (14) explain the variation of temperature difference between the metal and saturated steam for step rise in heat input.

Figure (15) exhibits the distribution of the void fraction that indicates a rapid increase in the first few seconds then followed by a continuous reduction in its value. As a result, the heat transfer coefficient decreases as shown in figure (12). This explains the behavior of the heat transfer coefficient, h, in figure (12).

Figure (16) provides a comparison of the water level due to liquid and steam contents. The small differences are due to the steam contribution to water level. The present calculations and those of Kim and Choi [9] , show that the volume of bubble continue to increase at a lower rate rather than decreases .

Conclusions

The present model is used to investigate the dynamic effects of rapid changes in fuel flow rate on the overheating of the riser tubes in natural circulation water tube boilers. The system under consideration includes the drum, riser and down comer as its major components.
A numerical scheme for the solution of the governing differential equations was established. The dynamic response of the system's state

variables due to rapid changes in fuel flow rate and steam flow rate was investigated.

The results indicate that increasing the heat flux by 10% and by 20% can lead to high variations in pressure, steam quality and water level in the drum. As well, the changes in the heat transfer coefficient lead to a temperature increase in the riser metal temperature.
The riser temperature increases due to the increase in the steam temperature and due to the dynamic influence resulting from increase in the heat flux .The experimental and theoretical results of the water level in the drum are in reasonable comparison and with Kim and Choi [9] results.

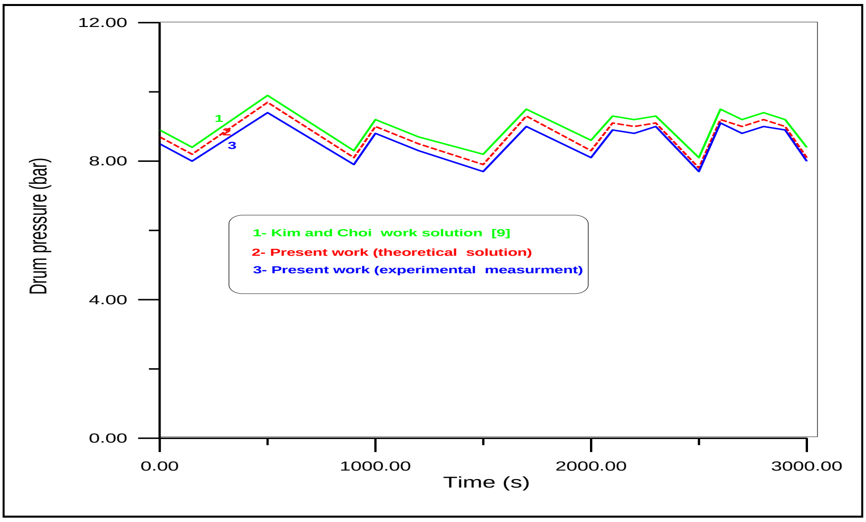

Figure (3) Response of drum pressure to variations in firing rates

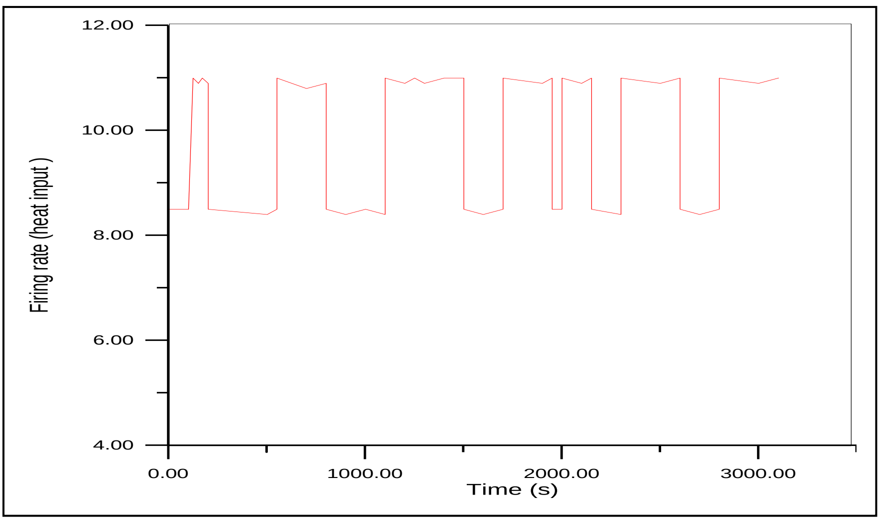

Figure (4) Experimental measurements for distribution firing rate

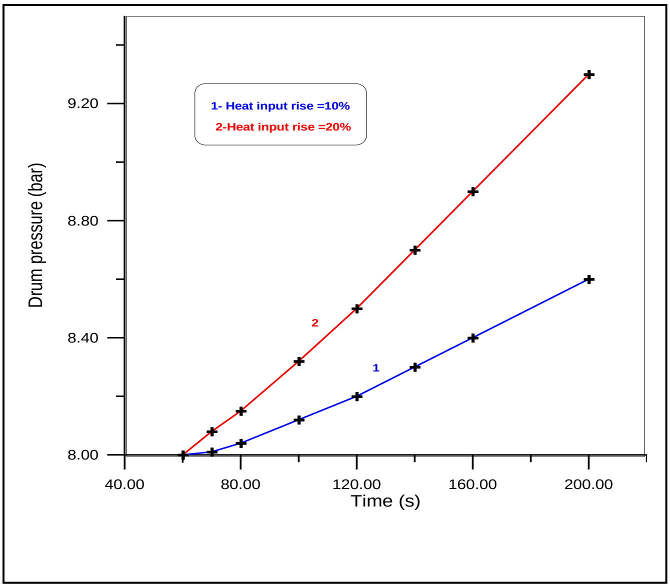

Figure (5) Variation of drum pressure for step rise in heat input

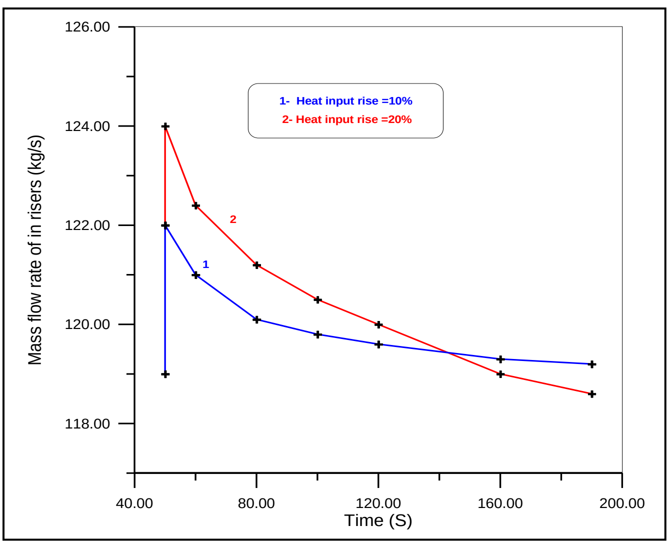

Figure (6) Variation of mass flow rate in risers for step rise in heat input

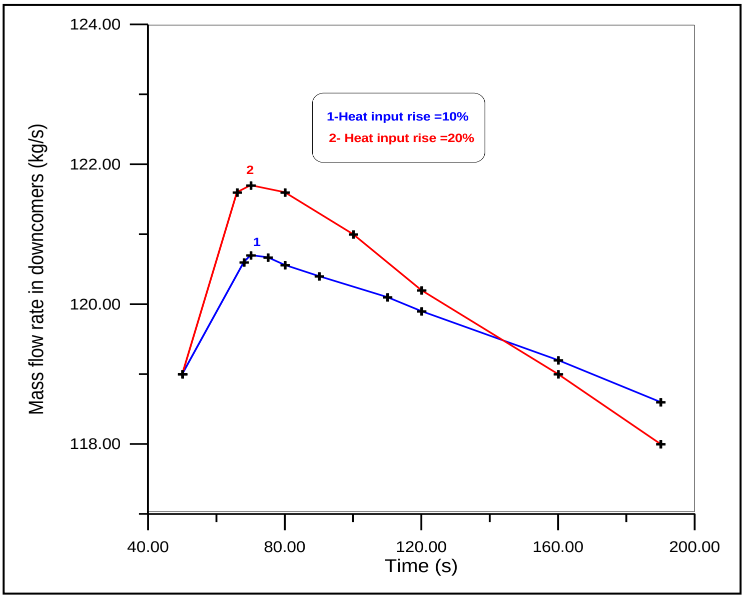

Figure (7) Variation of mass flow rate in downcomers for step rise in heat input

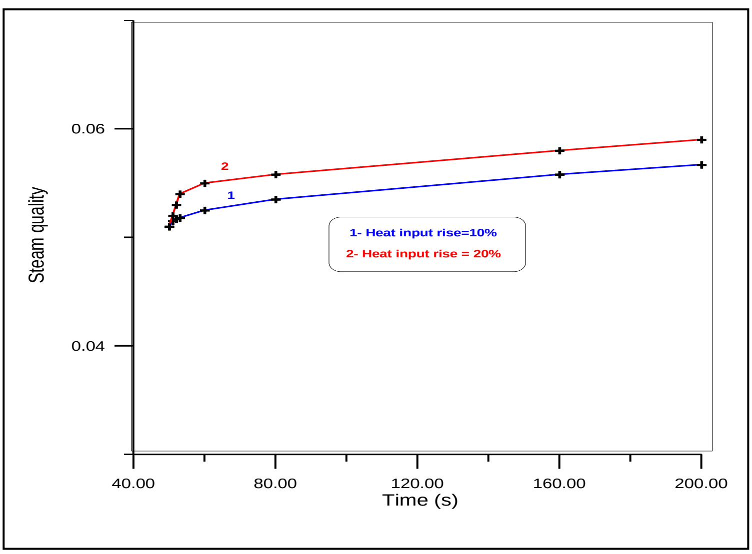

Figure (8) Variation of steam quality for step rise in heat input

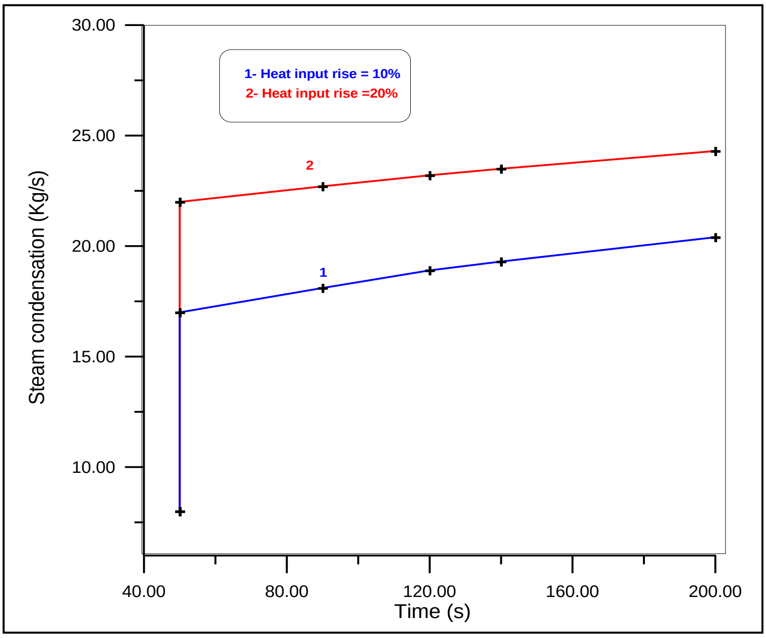

Figure (9) Variation of steam condensation for step rise in heat input

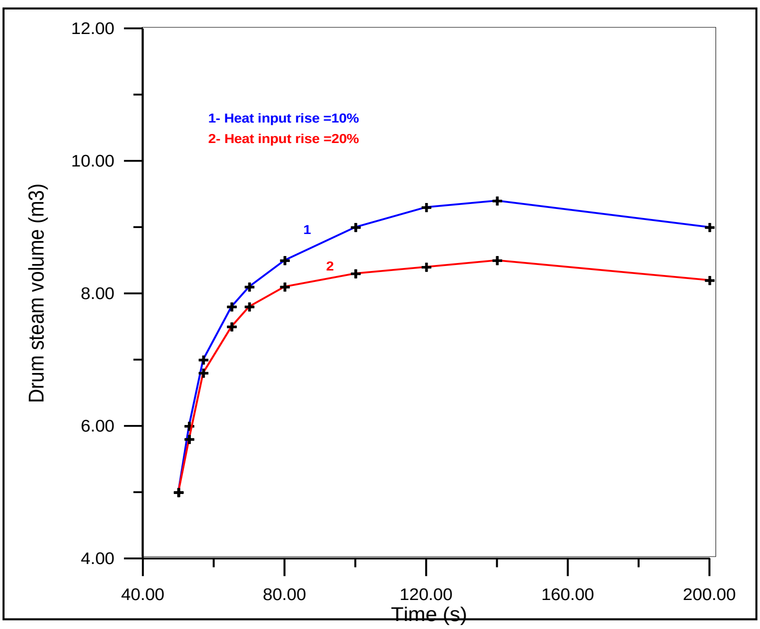

Figure (10) Variation of steam volume for step rise in heat input

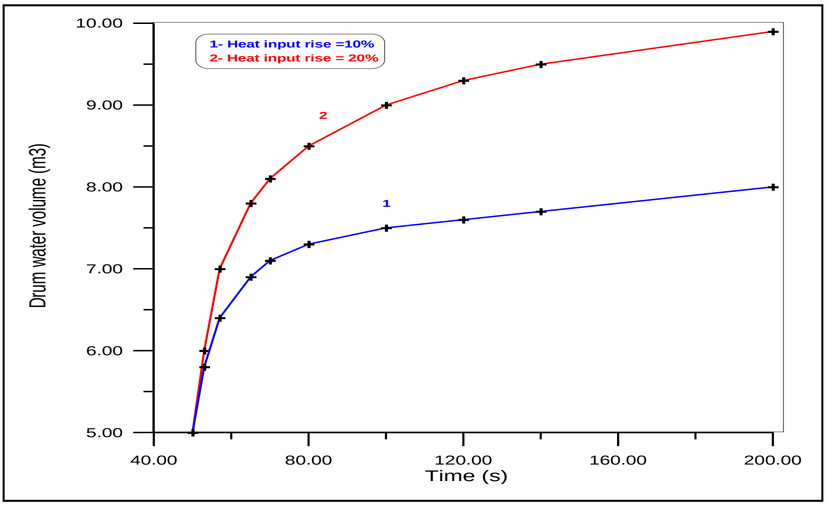

Figure (11) Variation of water volume for step rise in heat input

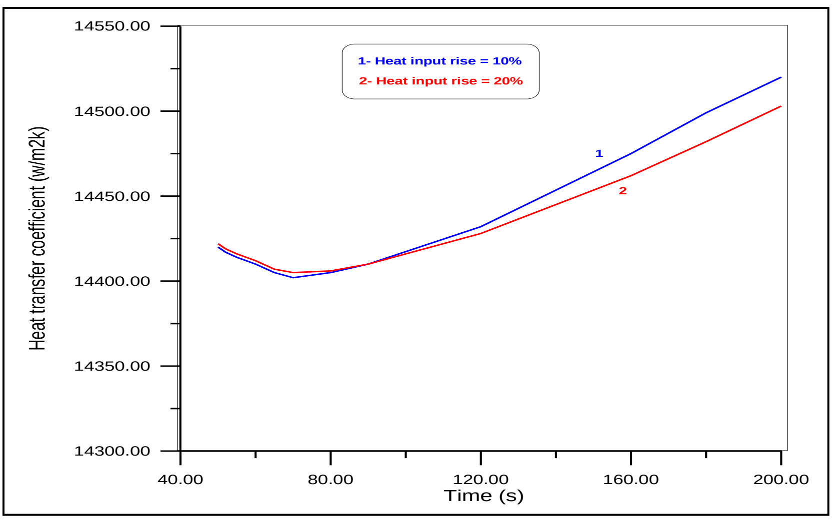

Figure (12) Variation of heat transfer coefficient for step rise in heat input

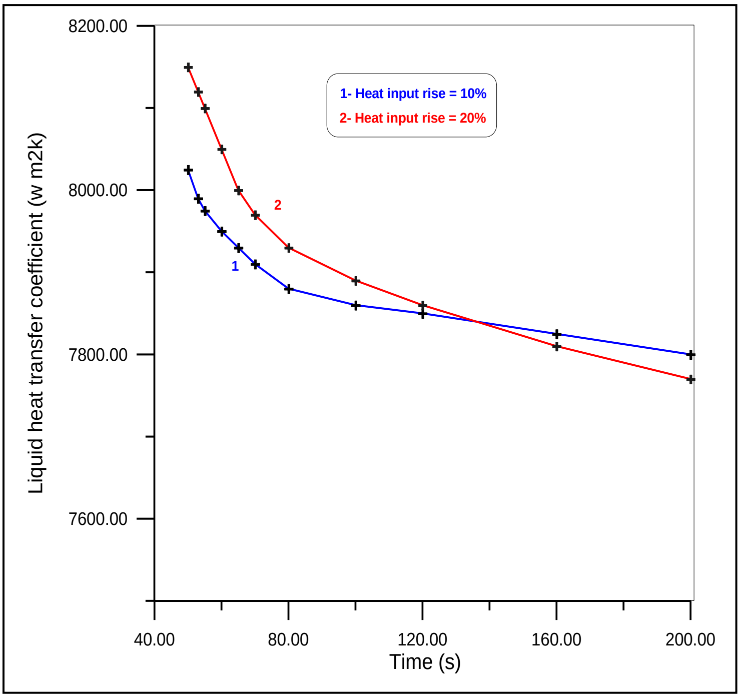

Figure (13) Variation of liquid heat transfer coefficient for step rise in heat input

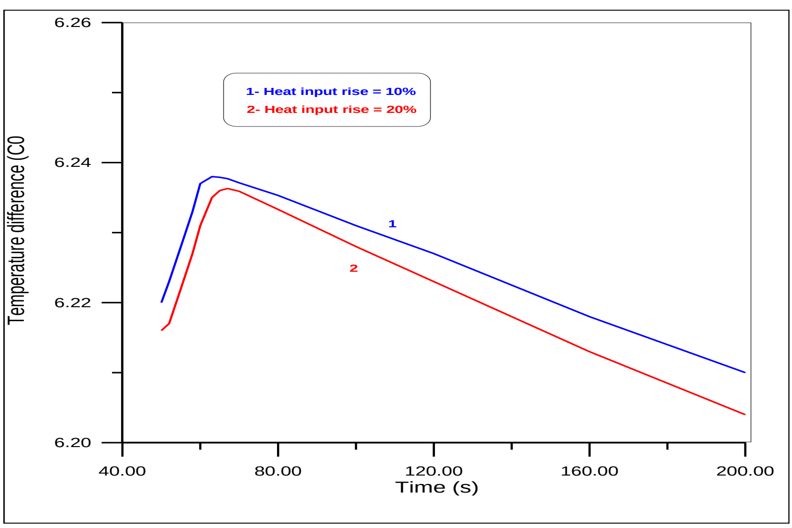

Figure (14) Variation of temperature difference between the metal and saturated steam for step rise in heat input

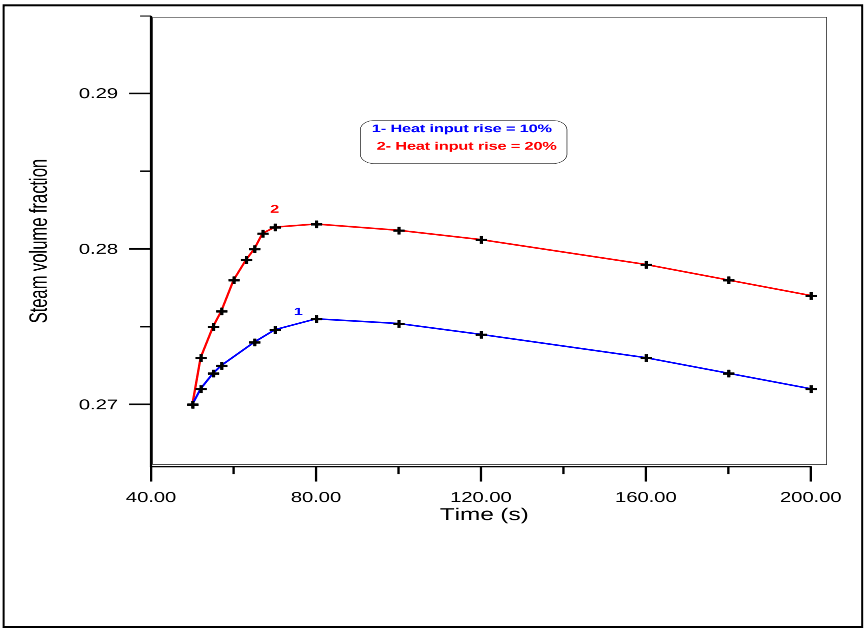

Figure (15) Variation of steam volume fraction for step rise in heat input

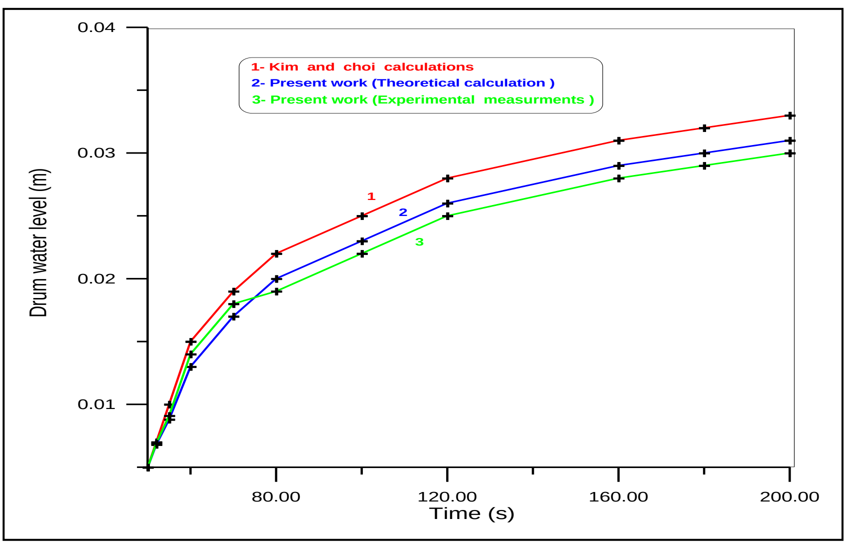

Figure (16) Comparison of drum water level Variation for step rise in heat input

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Nomenclature:

A_d -The drum area at normal operating level (m^2)

C_p - Specific heat at constant pressure (kJ/kg.k)

D_i , D_o - inter and outer drum diameter (m)

h_{fg} - $h_{fg} = h_g - h_f$ (kJ/kg)

h_c - Condensation enthalpy (kJ/kg)

h_f - Specific enthalpy of saturated liquid water (kJ/kg)

h_s - Specific enthalpy of steam (kJ/kg)

h_g - Specific enthalpy of saturated water vapor (kJ/kg)

h_w - Specific enthalpy of feed water (kJ/kg)

K - Friction coefficient in down comer-riser loop

L - Drum water level (m)

L_s - Level variations caused by changes of the amount of steam in the drum (m)

L_w - Level variations caused by changes of the amount of water in the drum (m)

m_s - Mass flow rate of steam exiting the boiler to turbine (kg/s)

Q_s - m_W - Mass flow rate of water (kg/s)

Q - Heat flow rate (kJ/h)

Q_f - Feed water flow rate (kJ/h)

t_d - Residence time of the steam in the drum (s)

T_s - Saturation temperature for steam (C0)

V_d - Volume of boiler drum (m3)

V_{dc} - Volume of down comer (m3)

V_r - Volume of riser (m3)

V_{sd} - Volume of steam in drum (m3)

$V^0{}_{sd}$ - Volume of steam in drum at equilibrium (m3)

V_{wd} - Volume of water in drum (m3)

V_{wt} - Total volume of water in drum (m3)

X - Mass fraction of steam in the flow (-)

Greek symbol

α - Volume fraction of steam in the flow (-)

β - Parameter in empirical formula (-)

ρ_g - Density of saturated steam (kg/ m3)

ρ_w - Density of water (kg/ m3)

تأثيرات الارتفاع السريع للحرارة الداخلة على خصائص أنابيب مولد بخار المحطة البخارية

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المستخلص

يختص هذا البحث بدراسة نظرية وعملية للتأثيرات الديناميكية للارتفاع السريع للحرارة المجهزة على خصائص الأنابيب الداخلية لمولد بخار المحطة البخارية. الجانب النظري تم فيه حساب معامل انتقال الحرارة ودرجات الحرارة الداخلية والخارجية لجدران أنابيب مولد البخار وتم حل المعادلات الحاكمة للموديل الرياضي لمولد البخار عدديا. الجانب العملي تم تطبيقه على المحطة البخارية التجريبية الايطالية الصنع والموجودة في جامعة دمشق حيث تم قياس أهم متغيرات الاسطوانة العليا لمولد البخار عند زيادة معدل الاحتراق بنسبة 10%و20%. بينت نتائج هذه الدراسة إن الزيادة السريعة لمعدل الاحتراق يسبب زيادة في معدل التبخر مما يؤدي إلى زيادة حجم الفقاعات الهوائية ووصولها إلى منطقة انفصال البخار عن الماء مسببة اضطرابا لمتغيرات الاسطوانة العليا . كذلك بينت النتائج إن ارتفاع درجة الحرارة فوق درجة حرارة الإشباع ناتج من التأثير الديناميكي للارتفاع السريع للحرارة الداخلة . تمت مقارنة النتائج العملية والنظرية لهذه الدراسة وأعطت مطابقة جيدة وسلوكا مشابها لنتائج الباحثين كيم وجو وتم تمثيلها بيانيا

الكلمات الدليلية :- أنابيب ماء مولدات البخار، محطات بخارية، تأثيرات ديناميكية