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Reduction of Dynamic Effects in Upper Drum Boiler Using Control and Monitoring System

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ABSTRACT

Due to the disruption of the pressure in the upper drum, the mechanical and chemical effects in the boiler of steam power plants are a complex problem and hazardous. This work deals with an experimental investigation of the drum water level system in (Al-Quds power plant) in Baghdad / Iraq by increasing heat input and steam mass flow rate with ratio 10% and 20% to investigate the dynamic behavior of the system under a given operating condition. The mechanical effect problem is solved by regulating the steam mass flow rate pressure disturbance in the upper drum. The processor is used to control and monitoring the water level and steam mass flow rate in the upper drum. The mathematical equations of the boiler model are solved. The results gave decreasing in shrink and swell dynamics effects after using a water/steam level sensor at 58% of the drum volume. Also, the results approved that the drum level response with firing rate and steam load change is faster. Finally, the enhancement in decreasing the disturbance pressure is 15% by using a monitor and controls.

KEYWORDS

Mechanical dynamic effects, Electro-Mechanical control, water tube boilers.

INTRODUCTION

The boiler can be defined as a sealed vessel in which water under intense pressure is transformed into steam using heat effect. Inside the boiler furnace, heat is sourced from the fuel's chemical energy, and it is the primary job of the boilers to transfer the generating heat to the water flowing in the most effective method [1]. The steam boilers are used in the plant to generate superheated steam and absorb the ultimate amount of heat emitted in the combustion reaction. Through the radiation conduction and convection process, the heat is transferred to the water inside the boiler. The relative percentage of each directly depends on the designed heat transfer surface, the type of boiler, and the fuel used [2]. The boiler has a cylindrical vessel shape; the water-steam interface possibly occurs where the boiler drum level should be in the safe operation mode .The most important problem in boilers is the dynamic effects in the upper drum due to the fluctuation in the pressure. Safe operation is always a critical issue to take into account to minimize the risk. Low drum level risk increases in the steam; the low risk in drum level is always preferable [3]. However, at a high drum level, water carries over into the steam header and decreases the steam. In the natural loop drum-type boilers, the water loop is critical in boiler technicality. Power plants need constant supervision and inspection at regular intervals. Errors in calculating the different phases are possible, involving individual employees, as well as the absence of Microcontrollers have a few characteristics. The traditional steam/water level in the upper drum boiler is a key parameter to calculate and monitor the function, but it is not automatic. [4, 2] The upper drum level must be automatically controlled in response to the many limits set by the steam boiler configuration.

There could be water mechanical carryover consequences if the upper drum steam/water level does not remain under these limits. Boiler water carryover into the super-heater or turbine, if the amount reaches the limits, can cause harm, resulting in high maintenance costs or turbine or boiler outages .Overheating effects of the water wall tubes can cause tube ruptures and severe accidents if the steam/water level is low, resulting in costly repairs, downtime, and injury or death to workers [5]. As the boiler load (steam demand) varies, dynamic shrink/swell occurs, causing fluctuations in the liquid surface level in the steam drum .The downstream mechanism regulates the flow of steam from the boiler. The strain in the steam drum and boiler circuit is affected by a sudden rise or decrease in steam flow. The boiling point and density of water and steam will both change as the pressure changes. The amount in the steam drum will quickly increase or decrease as a result of these simultaneous reactions [6]. The swell and shrink reactions are in the opposite direction of the boiler's natural activity. As a result, swell and shrink reactions wreak havoc on steam drum level power. The pressure in the boiler circuit will rise if the steam output from the boiler is abruptly decreased [7]. Due to a higher inflow than outflow, the drum level will initially shrink and then raise as the pressure rises. As the steam output from the boiler is abruptly raised, the opposite is real. Pressure fluctuations caused by unstable energy supply to the boiler will also induce the same swell and shrink reactions, making steam drum level control incredibly difficult [8].

The exact arrangement of steam-producing tubes in the boiler has a big impact on this action. Since, at least initially, the firing rate cannot rise quickly enough to meet the steam output rate at the current demand stage, a sudden rise in steam load would naturally result in a drop in pressure in the steam drum. The natural convection within the boiler is drastically affected as the pressure in the drum decrease [4, 6]. Under any load inside the boilers, the water within the drum, mud drums, and boiler tubes cohabit with the bleb of steam produced. If suddenly increased the request steam, the resultant development in steam flow from the drum makes a decline in pressure. As the function of drum pressure is the steam generation rate, the pressure decline instantly will cause extra steam. This indicates that extra steam bubbles are accompanying within the steam boilers water inventory while the steam inside the boiler to water ratio under water surface rises. Due to the steam already having a larger specific volume than water, the drum level rises swells till the supplementary steam generation's rate stabilizes [9]. Once the stabilizing rate is reached, the lack of balance of the mass flow between both the feed water and steam flows will lead to the drum level falling unless the feed water flows growing instantly. And this makes the drum level challenging to control. If the rush order for steam reduces immediately, the same effect, but the opposite manner occurs. Within this scenario, drum pressure fast boosts, decreasing the steam generation and steam-to-water ratio. This indicates the initial drops in the" drum" level till the new supplies of the steam-generating rate stabilize. The drum level will start to grow whenever the stem rate is stabilized, except if the feed water stream is decreased to settle with the latest steam flow rate immediately [10]. Figure 1 explains the drum level variation.

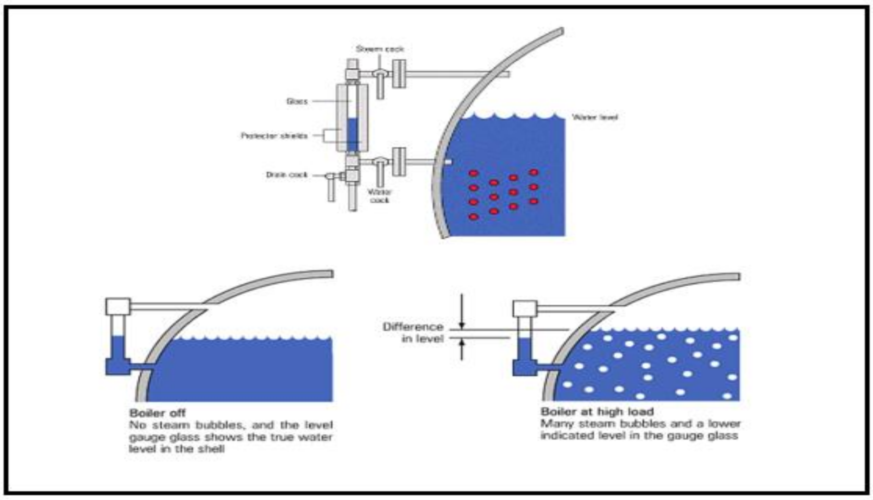

Figure 1. The drum level variation.

The drum has a complicated geometry. However, its behavior can be described by the wet surface (A_d) at the operational level. The deviation of the drum level (L) measured from its average operating level is [9]:

$$\boldsymbol{L = \frac{V_{wd}+V_{sd}}{A_d} = L_s + L_w} \tag{1}$$

The temperature/density of the water in the sight glass, affects the reading of the drum level indication, which is colder than the water in the boiler tank. Mechanical carryover occurs as the upper drum of the boiler fails to separate steam from the steam/water mixture, causing mechanical carryover [11].

Incomplete separation is caused by a variety of mechanical and chemical causes. High water volumes, load characteristics, firing system, or insufficient or leaking separation machinery, as well as boiler design, are all mechanical considerations [12]. Figure 2 explains the schematic diagram of drum boiler steam/water level with an additional control unit.

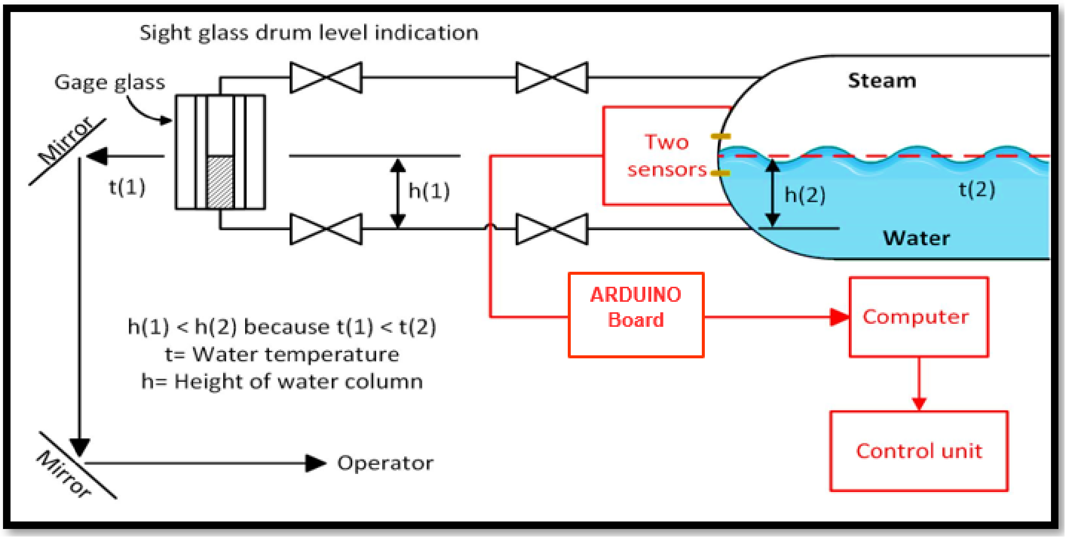

Figure 2. Schematic diagram of drum boiler steam / water level with an additional control unit.

The current work investigation of the dynamic response to pressure in the cylinder to fast changes in the fuel flow rate (heat input) and (the rate of steam mass flow), the measurement empirical of the upper cylinder parameters (pressure in the cylinder and cylinder water level) under this vacillation to improve the operation of the steam generated to inhibit overheating of the rising tubes, and laboratory station was designed and built to simulate industrial boilers and prototype of a monitoring system to control and monitor the whole system. By using LABVIEW Software to convert the signal of the water level sensor in the upper drum and apply the experimental part by Arduino controllers. In the existing system, the boiler's upper drum water level is monitored by using the ARDUINO UNO board and monitoring camera, it can be controlled only manually. The aim of this work is controlling and monitoring the water level in the upper drum to reduce the dynamic effects in the boiler.

MATHEMATICAL FORMULATION

It is very difficult to achieve the solution of mathematical equations as a synthesis of the mathematical description. In several phenomena, the number of variables, nonlinearities, and uncertainties contribute to the complexity of the problem [13]. The governing equations consist of the preservation of the total system's mass and energy, the phase shift in the drum boiler, including the volumes of water and steam within the drum boiler, and the rate of steam condensation and flow circulation in the riser-down comer loop, which controls the mass, energy and momentum transport [14,15].

$$\dot{m_w} - \dot{m_s} = a_{11}\frac{dV_{wt}}{dt} + a_{12}\frac{dP}{dt} \tag{2}$$

$$Q^{\cdot} + m_w h_w - m_s h_g = a_{21}\frac{dV_{wt}}{dt} + a_{22}\frac{dP}{dt} \tag{3}$$

$$a_{11} = \rho_f - \rho_g = \rho_{fg} \tag{4}$$

$$a_{12} = V_{wt}\frac{\partial \rho_f}{\partial P} + V_{st}\frac{\partial \rho_g}{\partial P} \tag{5}$$

$$a_{21} = \rho_f h_f - \rho_g h_g \tag{6}$$

$$a_{22} = V_{wt}\left(h_f \frac{\partial \rho_f}{\partial P} + \rho_f \frac{\partial h_f}{\partial P}\right) + V_{st}\left(h_g \frac{\partial \rho_g}{\partial P} + \rho_g \frac{\partial h_g}{\partial P}\right) - V_t + M_t C_p \frac{\partial T_s}{\partial P} \tag{7}$$

$$\dot{m_w} = \dot{m_s} \tag{8}$$

$$\dot{Q} = \dot{m_s}\,(h_g - h_w) \tag{9}$$

The governing equations of the firing rate in the furnace can be represented as the following [15,16]: -

$$\frac{d(m_g H_{gf})}{dt} = A\,.\,C_{pA}\,.\,TA + k_{comb}\,.\,B\,.H_{cn} - G_e C_{pg}\,.T_g - K_{Re}\,(T_m^4 - T_s^4) \tag{10}$$

Where A, B is the Air and fuel flow respectively, G_e- the evacuated gas, k_{comb} - the burning coefficient. At the saturation temperature Ts,The heat exchange to the furnace zone (convection, conduction, and radiation) and the water from pipes is equal to a direct thermal exchange throughout radiation. $T_m$is the heat moderate heat that belongs to the combustion gases from the low perfect gases.

$$m_g H_{gf} = \frac{V C_{vg} P_f}{R} \tag{11}$$

$$\frac{V C_{vg}}{R}\frac{dp_f}{dt} = .\,C_{pA}.TA + k_{comb}.B.H_{cn} - G_e C_{pg}.T_g - K{m^4}_{S}{}^{4}{}_{Re} \tag{12}$$

The increase of drum level signals typically generates less or more vapor bubbles in the water, and the drum amount remains unchanged. This condition causes the level shift during boiler load variation in the obverse direction of what is expected with a specific load alteration. The sight glass reading is affected by the water's temperature /density in the sight glass; the sight glass's water is lower temperature than the boiler drum's water [17]. Figure 3 effected of the bubbles on the drum level.

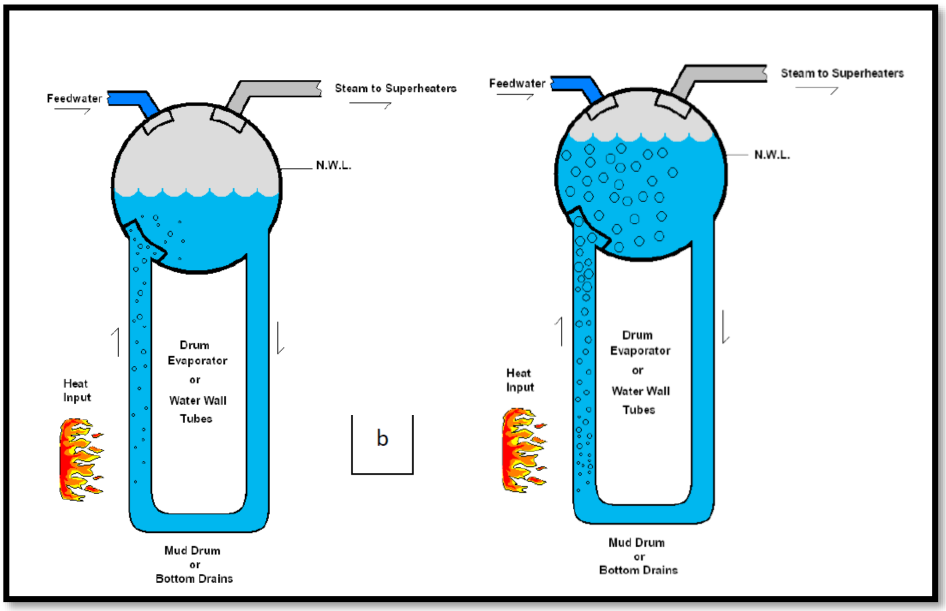

Figure 3. Effected of the Bubbles on the drum level.

EXPERIMENTAL PROCEDURE

This work's experimental procedure was applied to the steam generator of the boilers (Al-Quds power plant) in Baghdad / Iraq. The parameters were all measured when the plants at a thermal equilibrium state, and other data were registered from the steam generator's technical characteristics sheet.

Figure 4. The boiler in (Al-Quds power plant) Baghdad / Iraq

The experimental procedure work includes the study of the fundamental parameters as following:

MEASUREMENTS

Performed the increasing heat input (firing rate) by 10% and 20% , and examine the variations in drum water level and drum pressure in responding to this step variations in firing rate .The measurements provide the variations in firing rate with time.

MEASUREMENT OF DRUM LEVEL

The steam generation unit's drum level has a complex engineering design (length glass gauge 90 mm) [Figure (5)]. Reading the drum level from the glass gauge directly to register the drum level response with firing rate, synchronization, we estimate the drum pressure at increasing the firing rate by (10% and 20%). Can be described the liberalized behavior by the wet surface (A_d) at the functional level.

Figure 5. The water level gage in the (Al-Quds power plant).

DRUM PRESSURE MEASUREMENT

Figure 6 shows the drum pressure gage, usually the drum gage depends on the firing rate variation, i.e., heat input. The firing rate variation is possibly measured under a stabilization situation. The plant is let running for enough periods to stabilize till temperatures and steam pressures in the circuit's various points. The cooling water temperature at the condenser's outlet stays constant to starting measuring drum pressure. When stabilization is being achieved, the drum pressure measurements were recorded with a rising firing rate of 10% and 20%. At each variation, we had registered the gage value of the drum pressure with time.

Figure 6. The drum pressure gage in (Al-Quds power plant)

STEAM GENERATION MEASUREMENT

Figure 7shows the drum pressure gauge steam generator unit in the (Al-Quds power plant) Where Steam production is (21,000 kg / h) and the maximum steam pressure at normal operating is 10 bars. Drum pressure measurements are taken at a stabilization state with changes in steam load increasing (10 and 20 percent), with each shift the readings of the drum pressure gauge are taken and reported with time.

Figure 7. steam generator unit in the (Al-Quds power plant).

ARDUINO UNO BOARD

A microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins, 6 of which can be used as PWM outputs, 6 analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, a reset button and an ICSP header. Using this type of board and connected with liquid level controllers used for control the high or low water level in upper drum tanks, as shown in figure (8) and (9).

Figure 8. Arduino Uno board.

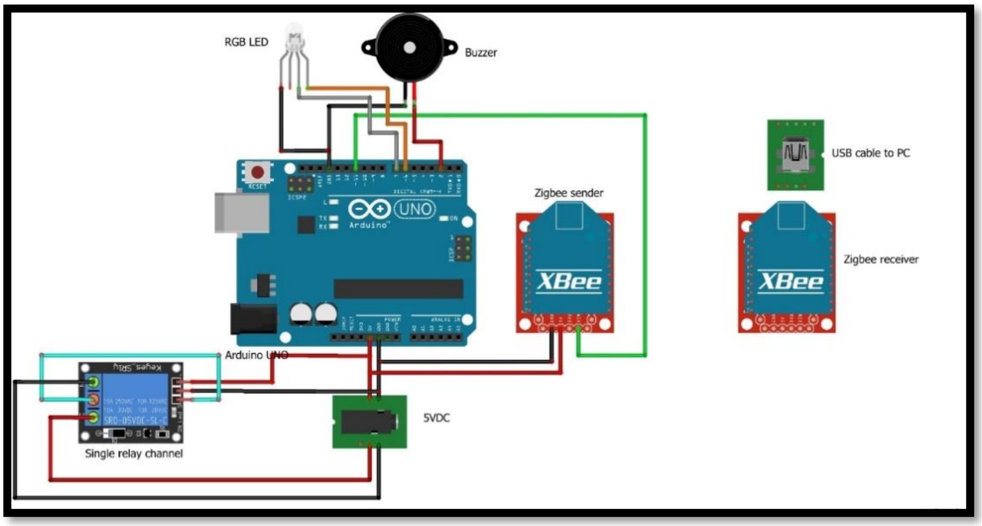

Figure 9. Schematic diagram of Arduino circuit.

INTERFACING BETWEEN LABVIEW AND ARDUINO

Figure 10. explained the diagram of the Interfacing procedure between LABVIEW and Arduino Uno board. LABVIEW software for design and implementation the experimental part of the software is thus used to provide a control structure and thus facilitates the fulfillment of the following tasks:

1 -Real-time control design and implementation algorithm.
2 -Through the human interface device works to manage the relationship between the system and the operator.
3 .Real-time monitoring of system activity.
4. Data analysis and recording.

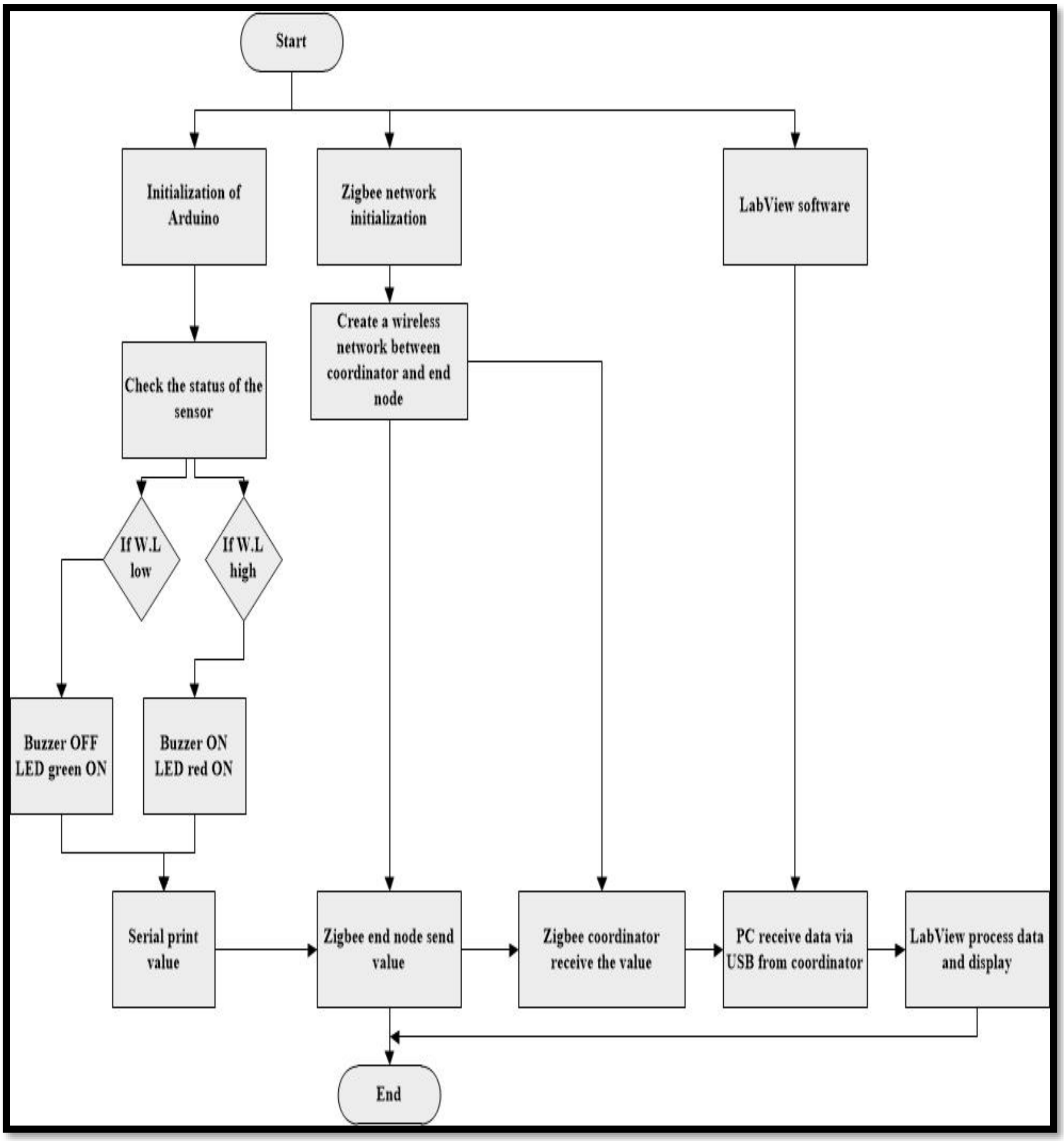

Figure 10. The diagram of experimental procedure.

RESULT AND DISCUSSION

Figure (11) explains how the pressure in the drum behaves when a sudden increase in heat input $\dot{Q}$. When the firing rate is at its highest, the drum pressure increases, allowing the firing rate to reach the mean by (2.1) minute due to an increase in heat input. As a result of a 10% step increase in the heat supply, the pressure increases at a steady rate of $dp/dt=$ 0.0314 bar/s. And the rate of pressure increases by 0.065 bar/s in the case of a 20% step increase in the heat supply. To explain the increase in drum pressure. When the firing rate rises, the amount of water volume inside the upper drum boiler rises as well, causing a disturbance (oscillation) in the drum pressure, indicating that the disturbance value in the minimum firing rate is less than the maximum firing rate.

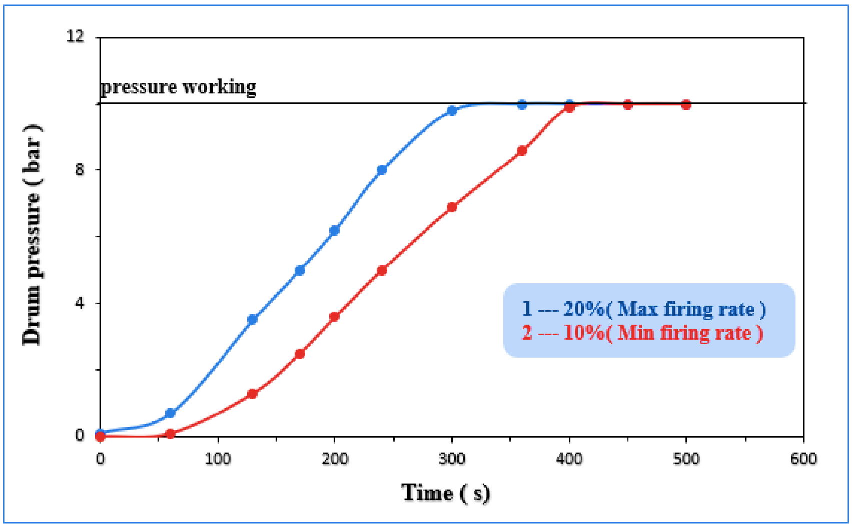

Figure 11. The drum pressure behavior with fuel firing rate variation.

Figure (12) shows steam - water level at the regular operation of fuel firing rate. The drum level is connected to the change in the fuel firing rate. However, the utmost significant reason for swell and shrink is the fast variation in drum pressure. Shrinking or expanding the steam bubbles due to load changes should be most concentrated. When there is a decrease in the steam request, it increases the drum pressure and the firing rate changes. Thus, reducing the volume of the bubbles (bubbles become smaller). When the drum pressure decreases, the steam and the boiling point of the water in the drum also drops, bubbles Generated (more bubbles). These rising bubbles lead to push up the water in the drum.

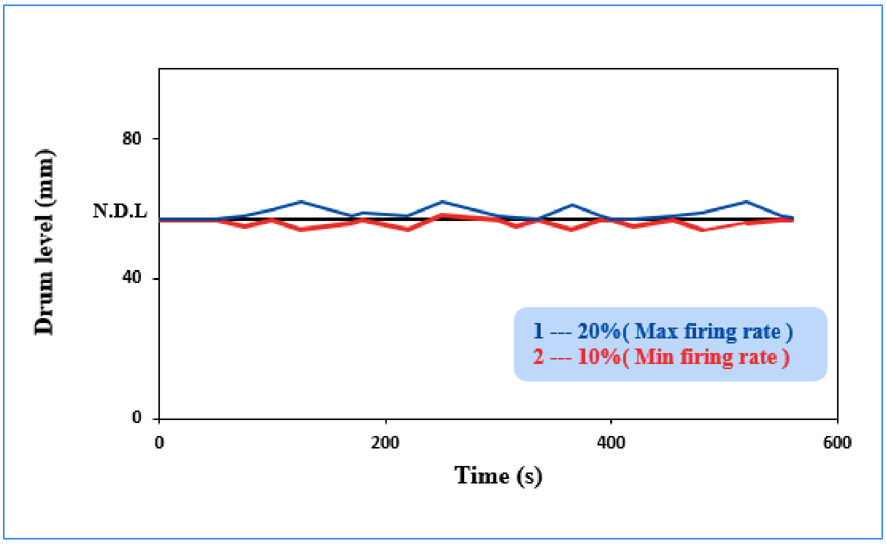

Figure 12. The response of steam - water level with fuel firing rate at normal operation.

Figures (13 and 14) demonstrate the influence of swelling phenomena of the rapid change of steam load with and without the control process. It is clear that when the steam load suddenly changes, the effects of swelling phenomena are increased and that the complex disruption in the water-steam level is increased. Also, the quick response for treating the issue of dynamic disruption in water/steam level resulted in reduced swelling phenomenon results when the control mechanism was used by 19.4% of the drum level.

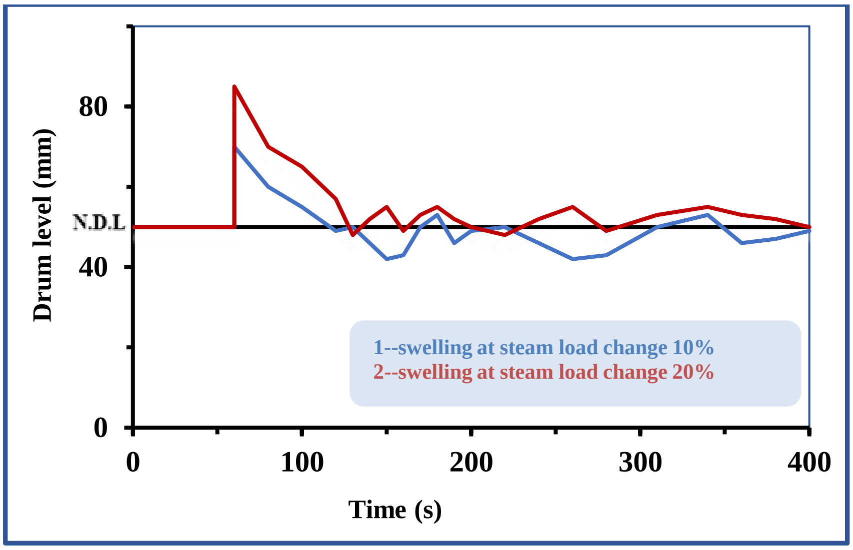

Figure 13. Effect of suddenly change of the load on swelling phenomena without control.

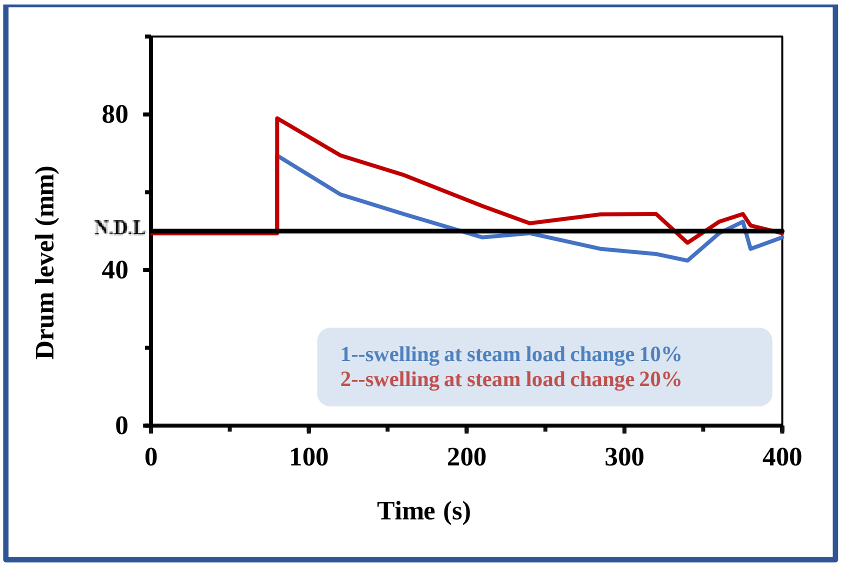

Figure 14. Effect of suddenly change of the load on swelling phenomena with control.

Figure (15 and 16) demonstrates the influence of shrinking phenomena of the rapid change of steam load with and without the control process. It is clear that when the steam load suddenly changes, the effects of shrinking phenomena are increased and that the complex disruption in the water-steam level is increased. Also, the quick response for treating the issue of dynamic disruption in water/steam level resulted in reduced swelling phenomenon results when the control mechanism was used, it was calculated that the decrease percentage would be 13%.

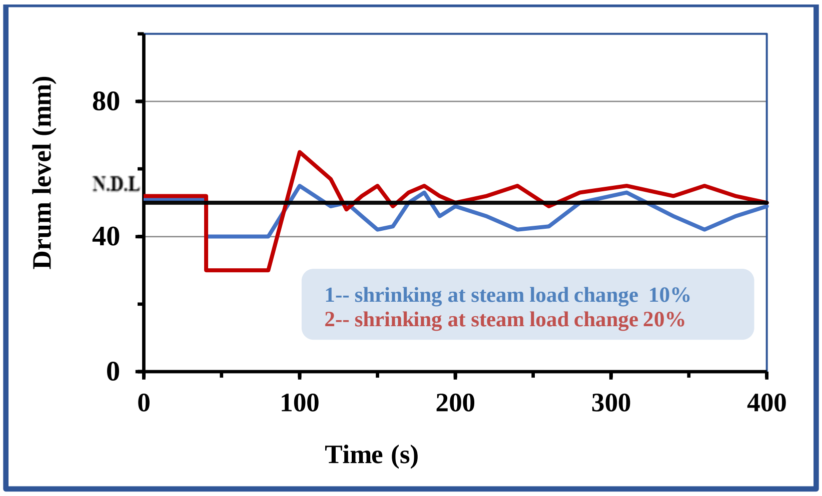

Figure 15. Effect of suddenly change of the load on shrinking phenomena without control.

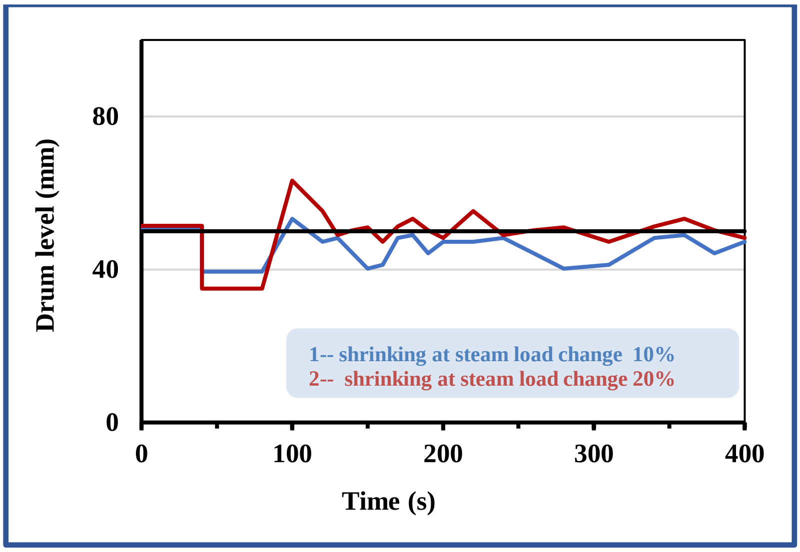

Figure 16. Effect of suddenly change of the load on shrinking phenomena with control.

CONCLUSIONS

A sudden rise in the loaded steam causes an increase in the upper drum's shrinking and swelling phenomena, when the temperature has increased, then the bubbling increases the volume of the drum and the water level will first go up, this work is concluded the following facts: -

1. The water level begins to go down as the steam mass flow rate increases.
2. An increase in the heat input (firing rate) causes an increase in drum pressure and the steam flow increased.
3. Drum level is very difficult to control because of the inverse response of the level to steam demand changes.
4. Due to the inverse response of the level to changes in steam demand, the drum level is hard to control.
5. To prevent overheating of the tubes, the drum level system must ensure that the water levels are always mainlined above the top of the risers/down comers.
6. Drum level fluctuations cause interactions with the controls of boiler combustion and can generate cyclical or even unstable boiler control, resulting in inefficient and dangerous operations.
7. If the level of the drum drops too low, the boiler may be damaged by thermal stress. If the level gets too high, some water particles may be carried by steam leaving the drum, which can cause harm to turbines or other steam users.
8. Using a monitoring camera and the Lab VIEW is to constantly track the parameter values in order to manipulate them. After using water and steam level sensor at a water level of 58 % of the drum volume, the shrink, and swell dynamics effect was reduced.

9. The performance enhancement in decreasing the disturbance pressure is 15% with using a monitor and controls the level.

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NOMENCLATURE OF SYMBOLS

A_d	the drum area at normal operating level	m^2
C_p	specific heat at constant pressure	KJ/kg.ºk
H_{gf}	(gas fluid enthalpy h_g - h_f)	KJ/kg
h_c	condensation enthalpy	KJ/kg
h_f	specific enthalpy of saturated "liquid" water	KJ/kg
h_g	specific enthalpy of "saturated" water vapor	KJ/kg
h_w	specific enthalpy of feed water	KJ/kg
L	The drum water level	m
L_s	Variations in the level causes by changing of the amount of the steam in the drum	m
L_w	Variations in the level causes by changing of the amount of the water in the drum	m
m_g	The mass of saturated steam in drum and water walls	-
$\dot{m_s}$	mass flow rate of steam exiting the boiler to the super heater and turbine	Kg/s
$\dot{m_w}$	mass flow rate of feed water	Kg/s
$\dot{Q}$	heat flow rate	KJ/h
T_s	saturation temperature for steam	C^0
V_{dc}	volume of down comer	m^3
V_{sd}	The volume of steam in drum	m^3
V_{wd}	The volume of water in drum	m^3
V_{wt}	Total volume of water in drum	m^3
V_{st}	Total volume of steam in drum	m^3
ρ_f	density of saturated liquid	Kg/ m^3
ρ_g	density of saturated steam	Kg/ m^3
ρ_w	density of water	Kg/ m^3
ρ_{fg}	Difference between vapor and liquid	