

## Reduction of Chemical Effects of Swelling and Shrinkage Phenomena of a Boiler in Steam Power Plants Using Silicon Antifoam

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### ABSTRACT

The swelling /shrinkage are complex phenomenon in the steam power plants. One of the important reasons is the chemical effects, which causes a bubble formation and hence serious foaming carryover problems in the boiler. The present work is devoted to study and measure the chemical effects of the swelling and shrinkage phenomena due to the disturbance of the variables in the drum boiler of steam generation unit. The problem was studied and analyzed to find a suitable solution to reduce the foaming carryover, and hence to control the swelling and shrinkage phenomena. The theoretical part is describing the mathematical model for the boiler variables. The drum pressure and drum level at different load demands of boiler were measured experimentally. The feed water was treated carefully in order to study the reduction of foam produced from a small amount of lubricant oil in the boiler water. The foam was treated using silicon antifoam [SN 6010]. The experimental results proved that the silicon antifoam is efficient to remove the foam completely and then reduce the disturbance in the pressure by 18.6% and the reduction in swelling and shrinkage was by 29.4%, and 16% respectively.

**Keywords:** Chemical Effects, Foaming, Carryover, Steam Power Plants.

### تقليل التأثيرات الكيميائية لظاهرة الانتفاخ والانكماش على المرجل في المحطات البخارية باستخدام مانع الرغوة السليكوني

#### الخلاصة

ظاهرة الانتفاخ والانكماش هي مشكلة معقدة في محطات توليد الطاقة البخارية . احد الاسباب المهمة هي التأثيرات الكيميائية والتي تكون الفقاعات مسببة مشكلة الحمل الزائد في المرجل . العمل الحالي مكرس لدراسة قياس التأثيرات الكيميائية لظاهرة الانتفاخ والانكماش الناتجة من الاضطراب في المتغيرات في الاسطوانة العليا لوحدة توليد البخار . تم دراسة المشكلة وتحليلها ليجاد الحل المناسب لتقليل الرغوة والحمل الزائد للسيطرة على ظاهرة الانتفاخ والانكماش . الجزء النظري يصف موديل رياضي لمتغيرات المرجل المتضمن كافة المعادلات للدخول والخروج

وميكانيكية تكون الفقاعة المسببة للرغوة . الضغط وارتفاع مستوى الماء في الاسطوانة العليا للمرجل تم قياسهما عمليا بواسطة مقياس للضغط في اعلى الاسطوانة يستخدم لقياس الضغط وانبوية زجاجية مدرجة موضوعة بجانب الاسطوانة لقياس مستوى الماء. الماء الداخلى للمرجل تم معالجته بعناية للتأكد من ان كافة التأثيرات الكيميائية هي في حالة مقبولة لدراسة تقليل الرغوة الناتجة من وجود كمية قليلة من زيت التزييت في ماء المرجل . تم معالجة الرغوة باستخدام مانع الرغوة السليكوني SN6010. النتائج العملية اثبتت ان مانع الرغوة السليكوني كفوء لازالة الرغوة الحاصلة تماما وبالتالي التقليل من الاضطراب في الضغط بنسبة 18.6% وبالتالي التقليل من ظاهرة الانتفاخ والانكماش بنسبة 29.4% و 16% على التوالي.

## INTRODUCTION

The boiler is a closed vessel in which water under pressure is transformed into steam by the application of heat. In the boiler furnace, the chemical energy in the fuel is converted into heat, and it is the function of the boiler to transfer this heat to the contained water in the most efficient manner [1]. The boiler should also be designed to generate high quality steam for plant use. A boiler must be designed to absorb the maximum amount of heat released in the process of combustion. This heat is transferred to the boiler water through radiation, conduction and convection. The relative percentage of each is dependent upon the type of boiler, the designed heat transfer surface and the fuel [2].

The cylindrical vessel where the water-steam interface occurs is called the boiler drum. Boiler drum level is a critical variable in the safe operation of a boiler. A low drum level risks uncovering the water tubes and exposing them to heat stress and damage. High drum level risks water carryover into the steam header and exposing steam turbines to corrosion and damage.

## DRUM PRESSURE AND DRUM LEVEL VARIATION

At any given load, the water within the drum, boiler tubes and mud drum coexists with the bubbles of steam that are being generated. If the demand for steam suddenly increases, the resultant increase in steam flow from the drum causes a drop in pressure. Since steam generation rate is a function of drum pressure, the drop in pressure instantly causes more steam to be produced. This means that more steam bubbles are coexisting within the water "inventory" of the boiler and the steam-to-water ratio below the water surface increases. Because steam has a greater specific volume than water, the drum level rises or "swells" until the new steam generation rate stabilizes. Once the new steaming rate does stabilize, the mass flow imbalance between the feed water and steam flows will cause the drum level to quickly drop unless the feed water flow is increased. This makes controlling of the drum level difficult.

If the demand for steam suddenly decreases, a similar but opposite effect occurs. In this scenario, drum pressure instantly increases thus reducing the steam generation rate and steam-to-water ratio. This means that the drum level initially falls or "shrinks" until the new steam generating rate stabilizes. Once stabilized, the drum level will quickly begin to rise unless the feed water flow is reduced to balance with the new steam flow rate. [3]

**SWELLING AND SHRINKING PHENOMENA**

Dynamic shrinking/swelling is phenomenon that produce variations in the level of the liquid surface in the steam drum whenever boiler load (changes in steam demand) occur. This behavior is strongly influenced by the actual arrangement of steam generating tubes in the boiler [4]. A sudden steam load increase will naturally produce a drop in the pressure in the steam drum, because, initially at least, the firing rate cannot increase fast enough to match the steam production rate at the new demand level. When the pressure in the drum drops, it has a dramatic effect on the natural convection within the boiler. The drop in pressure causes a small fraction of the saturated water in the boiler to immediately vaporize, producing a large amount of boil-up from most of the tubes in the boiler. However, the level controller senses a rise in the level of the steam drum and calls for a reduction in the flow of feed water to the boiler [5, 6].

**BOILER DRUM LEVEL**

Swelling and shrinkage are a result of pressure changes in the drum changing water density. The water in the drum contains steam bubbles similar to when water is boiled in our homes. Boiler drum level maximizes steam quality and maintains proper drum level to prevent damage to boiler. Drum level measurement is shown in Figure (1) [7]. During a rapid increase in load, a severe rise in level may occur because of an increase in volume of the bubbles. This increased volume is the result of a drop in steam pressure from the load increase and the increase in steam generation from the greater firing rate to match the load increase (i.e., bubbles expand) as shown in Figure (2). If the level in the drum is too high at this time, it may result in water carryover into the super heater or the turbine. The firing rate cycle can result in drum pressure cycles. The drum pressure cycles will cause a change in drum level. This phenomenon is known as swelling and shrinkage [7]. The drum has a complicated geometry. However, its 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:

$$L = \frac{V_{wd} + V_{sd}}{A_d} = L_s + L_w \quad \dots \quad (1)$$

Shrink and swell refer to a decreased or increased drum level signal due to the formation of less or more vapor bubbles in the water, and no change in the amount of water in the drum. This condition produces level changes during boiler load changes in the opposite direction of what is expected with a particular load change. The sight glass reading is affected by the temperature /density of the water in the sight glass, the water in the sight glass is cooler than the water in the boiler drum [7, 8].

**CARRYOVER OF BOILER WATER**

Carryover is a general term used to describe moisture and entrained boiler water solids which pass over with the steam from the boiler to turbines and process systems .Foaming and priming in the boiler steam drum are causes of carryover

Foaming is the formation of small, stable bubbles on the steam release surface. This may be due to excessive levels of dissolved and suspended solids in the boiler water, high alkalinities and oil, process and other organic contamination. Priming is the mechanical lifting or surging of boiler water into the steam outlet. While foaming is related to levels of chemical constituents or process contaminants in the boiler water. Priming occurs as a result of mechanical and /or operating factors. Defective steam separation equipment, high water levels in the steam drum, boiler operation above its rated capacity, and sudden increases in boiler load are causes of priming. A special case of boiler carryover not included in either foaming or priming is silica volatilization which occurs as pressure (temperature) of the boiler increases above 600 psig, resulting in selective vapor carryover of silica with the steam [8,9].

Carryover results from incomplete separation of steam from the steam/water mixture in the boiler. Many factors, both mechanical and chemical, contribute to incomplete separation. Mechanical factors include boiler design, high water levels, load characteristics, method of firing, or inadequate or leaking separating equipment. Certain types of boilers traditionally produce consistently clean steam; other types are troublesome. Factors that affect carryover include design pressure, steam drum size, generating rate, circulation rate, arrangement of down comers and risers, and the type of mechanical separating equipment used. In some older water tube boiler designs, the steam carrying or riser tubes discharge below the water level, causing severe turbulence within the steam drum. This condition is minimal for units in which the steam generating tubes discharge above the working water level or beneath a baffle that separates them from the drum water, operation at loads in excess of design rating can increase carryover [9, 10]. A sudden increase in process steam demand may lower the steam header pressure and, in turn, the boiler drum pressure, causing rapid expansion of the steam/water mixture in the boiler. This can significantly raise the drum water level and cause carryover. One should avoid sudden changes in boiler operation whenever possible. Operating a boiler significantly below design pressure is often an overlooked cause of carryover [11].

Problems resulting from carryover of entrained or vaporous boiler water solids include:

- 1- Low BTU value steam, in essence, wet steam.
- 2- Super heater deposits and failures.
- 3- Turbines blade deposits and losses in efficiency.
- 4- Process contamination.
- 5- Corrosion /erosion of valves, steam traps, turbine parts and other steam-using equipment.

#### **CHEMICAL CARRYOVER**

Among the chemical causes of carryover are excessive alkalinity, high total solids concentration (dissolved and / or suspended solids) and the presence of oily materials and other organic contaminants. Methods of external and internal treatment can also affect steam purity, in certain instances, vaporization of solids may occur-another form of chemical carryover [10]. Foaming and selective vaporous carryover are the two basic mechanisms of chemical carryover.

Foaming is the formation of stable bubbles in boiler water. Figure(3) shows boiler water mist formation [10], because bubbles have a density approaching that of steam, they are not readily removed by steam purifying equipment. Foaming has caused erroneous water level readings that produce swings in feed water flow. Foaming tendencies of boiler water increases alkalinity, TDS, and TSS [10].

Oil and other organic contaminants in boiler water can cause foaming and severe carryover conditions. The alkalinity of the boiler water in the presence of fatty acids produces a crude soap that causes foaming. No method of internal treatment can overcome carryover problems caused by oil and other organics. In order to solve the problem, it is necessary to remove the contaminants from the boiler feed water. Frequently, the cause of a carryover problem cannot be economically corrected through adjustment of boiler water balances or installation of additional external treatment facilities. In many of these instances, the use of effective antifoam agent can reduce carryover tendencies significantly [11,12].

#### **METHODS OF CARRYOVER PREVENTION**

Methods used to prevent carryover include:

- 1- Control of boiler water level and load swings.
- 2- Control of steaming load within rated capacities.
- 3- Proper firing distribution.
- 4- Installation and maintenance of steam separation equipment.
- 5- Control of boiler water dissolved and suspended solids by blow down .
- 6- Control of boiler water chemistry.
- 7- Elimination of oil, process or other organic contamination.
- 8- Addition of chemical antifoams.

#### **ANTI-FOAMS**

There is an extremely diverse set of chemical formulations that can be effective either to prevent foam (anti-foam) or to destroy it once it has formed (defoamer). Actually the distinction between these two terms is usually ignored [13]. The most universal characteristic of any antifoam is the fact that it is surface active, but highly soluble in water. It has to be formulated so that it will be dispersed as tiny droplets, i.e: as an emulsion. The surface active nature of the material causes it to spread very rapidly onto any air-water interface that it encounters. This is especially the case if that interface is already converted by the types of surface active materials that tend to stabilize foams. Some, but not all antifoams contain hydrophobized silica particles or ethylene-bis-stearamide particles. The function of such particles is to pierce the surface of foam bubbles, causing them to coalesce when the antifoam spreads at the interface as shown in Figure (4) [14].

This work is aimed to study the effects of chemical foaming carryover on drum boiler of steam power plant, and to reduce swelling and shrinkage phenomena by adding silicon antifoam, and measuring of drum pressure and drum level of drum boiler experimentally.

**THE THEORETICAL PART**

This part is devoted to present the theoretical model used in this investigation.

**DRUM BOILER MODEL EQUATIONS**

A major difficulty in the boiler's dynamic behavior analysis is the fact that the whole system is very complex and contains numerous variables which are extremely the unwieldy to manipulate. The solution of the set of equations is difficult to obtain as the synthesis of the actual mathematical description. A large number of variables, nonlinearities, and uncertainties in many phenomena contribute to the complexity of the problem [15]. The system considered includes the drum, riser and down comer. 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. Thus, a set of four differential 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 [16] :-

$$a_{11} \frac{dV_{wt}}{dt} + a_{12} \frac{dP}{dt} = \dot{m}_w - \dot{m}_s \quad \dots (2)$$

$$a_{21} \frac{dV_{wt}}{dt} + a_{22} \frac{dP}{dt} = \dot{Q} + m_w h_w - m_s h_g \quad \dots (3)$$

$$a_{32} \frac{dP}{dt} + a_{33} \frac{dX}{dt} = \dot{Q} - x h_{fg} \dot{m}_{dc} \quad \dots (4)$$

$$a_{42} \frac{dP}{dt} + a_{43} \frac{dX}{dt} + a_{44} \frac{dV_{sd}}{dt} = \left(\frac{\rho_g}{T_d}\right)(V_{sd}^0 - V_{sd}) + \frac{(h_w - h_f)}{h_{fg}} \dot{m}_w \quad \dots (5)$$

The coefficients of these four equations are given by

$$a_{11} = \rho_f - \rho_g = \rho_{fg} \quad \dots (6)$$

$$a_{12} = V_{wt} \frac{\partial \rho_f}{\partial p} + v_{st} \frac{\partial \rho_g}{\partial p} \quad \dots (7)$$

$$a_{21} = \rho_f h_f - \rho_g h_g \quad \dots (8)$$

$$a_{22} = V_{wt} \left( h_f \frac{\partial \rho_f}{\partial p} + \rho_f \frac{\partial h_f}{\partial p} \right) + V_{st} \left( h_g \frac{\partial \rho_g}{\partial p} + \rho_g \frac{\partial h_g}{\partial p} \right) - V_t + MC_p \frac{\partial T_s}{\partial P} \quad \dots (9)$$

$$a_{32} = \left( \rho_f \frac{\partial h_f}{\partial P} - X h_{fg} \frac{\partial \rho_f}{\partial P} \right) (1 - \alpha) V_r + (1 - X) h_{fg} \frac{\partial \rho_g}{\partial P} + \rho_g \frac{\partial h_g}{\partial P} \alpha V_r + (\rho_g + X \rho_{fg}) h_{fg} V_r \frac{\partial \alpha}{\partial P} - V_r + M_r C_p \frac{\partial T_s}{\partial P} \quad \dots (10)$$

$$a_{33} = ((1 - X) \rho_g + X \rho_f) h_{fg} V_r \frac{\partial \alpha}{\partial x} \quad \dots (11)$$

$$a_{42} = V_{sd} \frac{\partial \rho_g}{\partial P} + \frac{1}{h_{fg}} \left\{ \rho_g V_{sd} \frac{\partial h_g}{\partial P} + \rho_f V_{wd} \frac{\partial h_f}{\partial P} - V_{sd} - V_{wd} + M_d C_p \frac{\partial T_s}{\partial P} \right\} + X(1 + \beta) V_r \left[ \alpha \frac{\partial \rho_g}{\partial P} (1 - \alpha) \frac{\partial \rho_f}{\partial P} + (\rho_g - \rho_f) \frac{\partial \alpha}{\partial P} \right] \quad \dots (12)$$

$$a_{43} = X(1 + \beta)(\rho_g - \rho_f) V_r \frac{\partial \alpha}{\partial x} \quad \dots (13)$$

$$a_{44} = \rho_g \quad \dots (14)$$

**STEADY STATE CONDITIONS**

The equations of equilibrium conditions are:-

$$\dot{m}_w = \dot{m}_s \quad \dots (15)$$

$$\dot{Q} = \dot{m}_s (h_g - h_w) \quad \dots (16)$$

$$\dot{Q} = X h_{fg} \sqrt{\frac{2 \rho_f A_{dc} (\rho_f - \rho_g) g \alpha V_r}{k}} \quad \dots (17)$$

**THE EXPERIMENTAL PART**

**Plant description**

The schematic diagram of Didacta Italia steam power plant is shown in Figure (5) which consists of the units :- 1- Ionic Exchange Demineralization plant unit ( B), 2- Boiler water supplying unit (C), 3- Steam generation unit (D), 4- Steam flow measuring unit (E) , 5 - Fuel feeding and measuring unit (H) , 6- Surface desuper heater (F), 7- Drying and pressure reducing unit (G), 8- Steam utilization unit ( I) , 9- Steam recovery unit by condensing (K), 10-Cooling tower unit (M) , 11- Deaerator ( N) .

**STEAM PLANT GENERATOR UNIT**

The technical characteristics of steam plant generator type 5/12 (Didacta Italia V10CFD) are shown in Table (1). Figure (5) shows a schematic diagram of all the parts and equipment of the steam generation unit.

**Table (1) The technical characteristics of steam plant generator.**

Steam production	$P_s$ Steam pressure	$P_T$ Steam temperature	$T_s$ min.	$T_s$ max.
750 kg/h	10 bar	12 bar	-10 °C	+225 °C

**The chemicals used**

In this work Silicon antifoam was used, as follows:-

**Silicon antifoam**

The main concern is to use the correct dosage, it is tested experimentally and it was found to be (1ml antifoam/ 1000 ml of water) added directly to the boiler water. The antifoam used in this study was silicon antifoam (SN 6010) provided by ORGANIK KIMYA, Turkey, its properties: solid materials 10%, specific gravity 1, appearance as white emulsion, dissolved in water. The reasons for choosing this antifoam are:

- 1-Availability.
- 2- Low price.
- 3-Can be used directly without any dissolving or diluting.
- 4- Suitable for all chemical processes and food industries.

**MEASUREMENTS OF IONIC EXCHANGE DEMINERALIZATION PLANT UNIT**

Water is the essential medium for steam generation. Conditioning it properly can increase the efficiency of boilers and as well as extend the boiler’s life. Treating boiler water also ensures safe and reliable operation, Table(2) shows tests of were, without proper treatment, severe problems can develop, some so severe that boiler itself can be destroyed. Boiler water problem generally falls into two classes: deposit related and corrosion related. Because the two often interact, it is very common to find a boiler experiencing both simultaneously. There are many instances where deposit causes corrosion and corrosion causes deposits. Therefore the aim of the boiler water treatment chemical is (1) To prevent the formation of scales and deposits on heating surface, (2) To prevent corrosion in the boiler and steam system, (3) To maintain high level of steam purity. The pressure and design of boiler determines the quality of water it requires for steam generation. The sequence of treatment depends on the type and concentration of the contaminants found in water supply and the desired quality of finished water to avoid three major problems in boiler systems – Deposits, Corrosion ,pitting and Carryover.

Table (2) The tests of water .

Type of test	Result of test	Accepted value	Device of test
PH	10.2	9.5-11	Electronic PH Meter
Chloride ppm	0.03	1 mg/g in the 0-100 range	HI3815 [ range of measurement (0-100)mg/L (ppm )]
Dissolved Oxygen ppm	0.001	must be (0.0)	Dissolved Oxygen Meter Model Do-5509 [range of measurement (0-20) mg/L ppm]
Total hardness ppm	0.002	must be < (0. 3)	HI3812 [range of measurement (0-30) mg/L ppm]
Total alkalinity ppm	235	must be < ( 700)	HI3811 [range of measurement (0-300) mg/L ppm]

#### MEASUREMENT OF DRUM PRESSURE

The drum pressure gauge (PI) in steam generation unit is shown in Figure (5). It changes at constant firing rate and steam demand (turbine load), so to measure the drum pressure, we start the plant at constant firing rate and let the plant run long enough to reach stabilization (45 minute), i.e. until steam pressure and temperature in the various points of the circuit and the cooling water temperature at outlet from the condenser remain constant. When stabilization is reached, the drum pressure is measured with and without silicon antifoam (SN 6010) through the following changes: - (i) - increase the steam load 10%, (ii) increasing the steam load 20%. At each change, the drum pressure is read from gauge (PI) with time.

#### MEASUREMENT OF DRUM LEVEL

The drum level has a complicated geometry (glass gauge 113 mm length). To measure the drum level response with silicon antifoam (SN6010) addition and without, drum level is read directly from the glass gauge (d11) with the same time of measuring the drum pressure while increasing the steam load (10% and 20%) with antifoam and without antifoam. This represents swelling phenomenon. The same procedure is repeated but in opposite i.e. drum level response with the following changes: (i) decreasing the steam load 10 % , (ii) decreasing the steam load 20%. This represents shrinkage phenomena with antifoam and without antifoam.

#### RESULTS AND DISCUSSION

Figures (6) to (8) shows the variation of drum pressure at normal operation, and at 10% and 20% steam demand. The results show a decreasing in oscillation of pressure when silicon antifoam is added because of foam bubbles are decreased . The reduction in oscillation of pressure is calculated from experimental measurements and it is found to be 18.6%.

Figures (9) and (10) show swelling at 10% and 20% steam demand respectively. They show that when adding a small amount of silicon antifoam [SN6010], the swelling decreases clearly, and reduction percentage was calculated to be 29.4%. On the other hand, if there is a sudden decrease in the demand for steam, there will be a temporary decrease in the drum level (shrinkage phenomena), Figures (11) and (12) show shrinkage at 10% and 20% respectively. Shrinkage was reduced by adding a small amount of silicon antifoam [6010], reduction percentage was calculated to be 16%. The function of silicon antifoam [SN 6010] is to cause foam bubbles to coalesce when it spreads at the interface to the point where they are large enough to float harmlessly to the water surface and break. This is the reason for more stabilization in drum pressure and drum level causing a reduction in swelling and shrinkage phenomenon, as shown in Figures (6) to (12).

### CONCLUSIONS

1. Shrink and swell are real phenomena in a boiler drum and cause a great deal of confusion for tuners and operators. If shrink and swell are not properly controlled damage and tripping of the unit can occur.
2. When the steam flow increases the pressure in the drum is reduced and the amount of bubbles increases. These extra bubbles cause an increase in volume and lift the water level in the drum and the level does rise. Shortly after this happens the steam flow increases and the mass inventory in the drum starts to drop.
3. When the temperature has increased, then the bubbling increases the drum volume and the level will first go up, then as the steam flow increases the level starts going down.
4. Shrink is the decrease in water volume due to an increase in pressure. In smaller drums, shrink becomes a real problem since the amount of water volume is so small. This can lead to overheating of the drum and tripping of the unit on low level.
5. When steam pressure drops rapidly. The drop in steam pressure itself causes additional entrainment and the interface between water and steam rises. This occurs because at the instantaneous lower pressure operation.
6. Drum level is difficult to control because of the inverse response of the level to changes in steam demand. The drum level system must ensure that the water level is always above the top of the risers/down comers to prevent overheating of the tubes.
7. The performance of the steam drum internals and chemical carryover is dependent on boiler water specifications, operating boiler pressure and water level.
8. Silicon antifoam is a good solution for the foaming carryover resulting from oil present in boiler water.
9. Silicon antifoam reduces the swell and shrink in drum boiler by the coalescing of foam bubbles.

**NOMENCLATURE:**

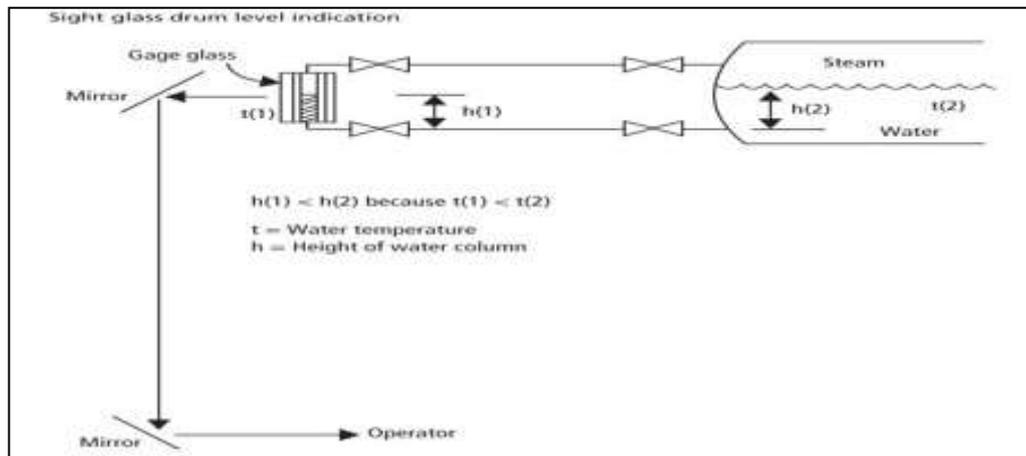
Symbol	Definition	Unit
$A_d$	the drum area at normal operating level	$m^2$
$C_p$	specific heat at constant pressure	$KJ/kg.k$
$a_{11} - a_{44}$	coefficients of the main model equations	-
$h_{fg}$	$h_{fg} = h_g - h_f$	$KJ/kg$
$h_c$	condensation enthalpy	$KJ/kg$
$h_f$	specific enthalpy of saturated liquid 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 the super heater and turbine	$Kg/s$
$\dot{m}_s$	mass flow rate of steam exiting the boiler to the super heater and turbine per unit time	$Kg/s$
$m_w$	mass flow rate of feed water	$Kg/s$
$\dot{m}_w$	mass flow rate of feed water per unit time	$Kg/s$
$\dot{m}_{dc}$	mass flow rate of feed water per unit time for down - comer	$Kg/s$
$P$	pressure	$bar$
$Q$	heat flow rate	$KJ/h$
$\dot{Q}$	mass flow rate of heat per unit time	$KJ/h$
$Q_f$	feed water flow rate	$Kg/h$
$Q_s$	steam water flow rate	$Kg/h$
$Td$	Temperature of the drum	$C^0$
$t_d$	residence time of the steam in the drum	$s$
$T_s$	saturation temperature for steam	$C^0$
$V_d$	volume of boiler drum	$m^3$
$V_{dc}$	volume of down comer	$m^3$
$V_r$	volume of riser	$m^3$
$V_{sd}$	volume of steam in drum	$m^3$

$V_{sd}^0$	volume of steam in drum at equilibrium	$m^3$
$V_{wd}$	volume of water in drum	$m^3$
$V_{wt}$	total volume of water in drum	$m^3$
$X$	mass fraction of steam in the flow	-
<b>Greek symbol</b>		
$\alpha$	Volume fraction of steam in the flow	-
$\beta$	parameter in empirical formula, $\beta = 0.3$	-
$\rho_g$	density of saturated steam	$Kg/ m^3$
$\rho_w$	density of water	$Kg/ m^3$
<b>Subscripts</b>		
$w$	water	
$s$	steam	
$g$	gas	
$d$	drum	
$r$	riser	
$p$	Pressure	
$t$	turbine	
$f$	saturated liquid water	

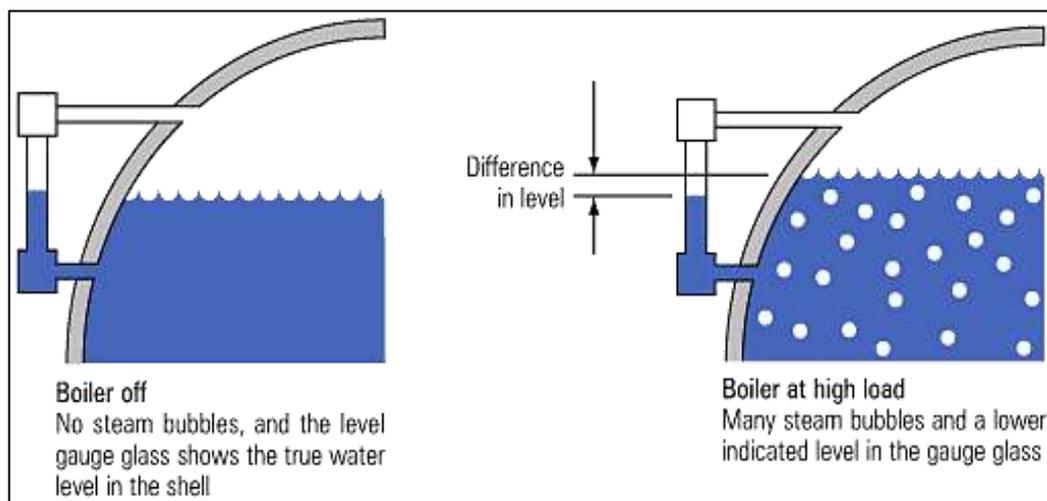
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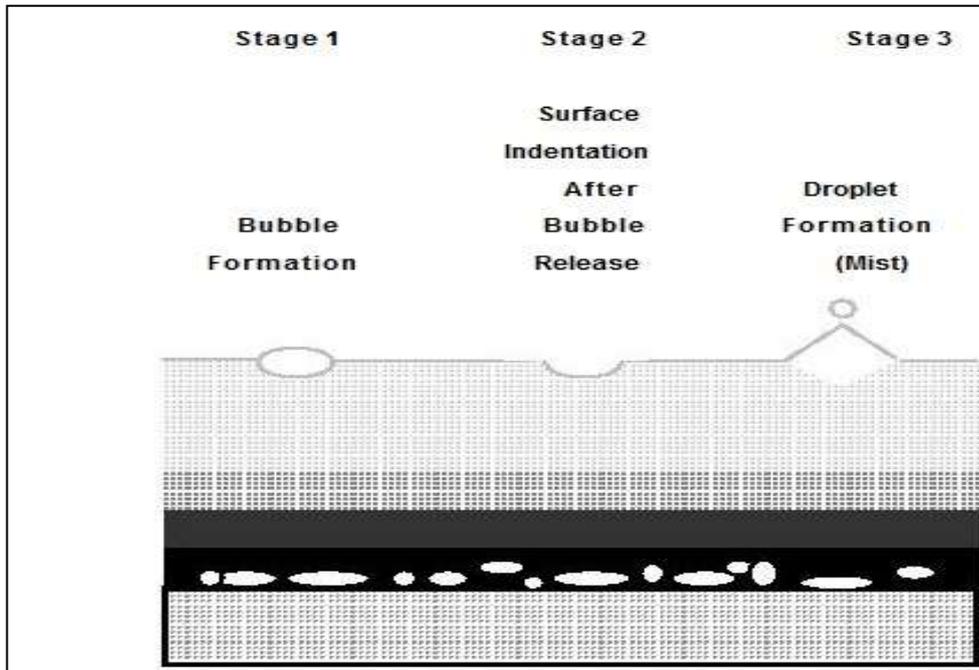
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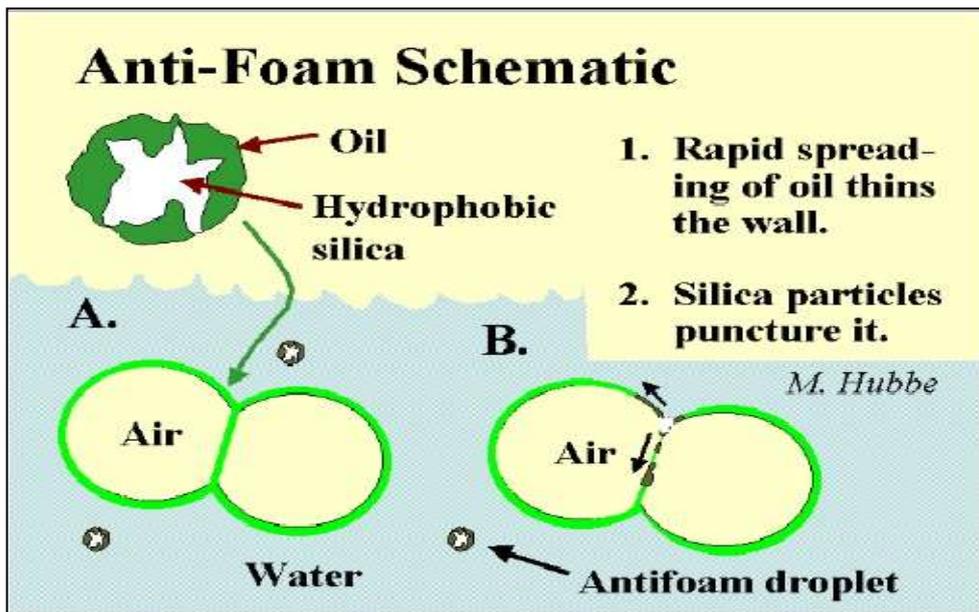
Figure(1) Drum level measurement.



Figure(2) Effect of bubbles on drum level.



Figure(3) Water boiler mist formation.



Figure(4) Anti-foam schematic.

الدارة الهيدروليكية للمحطة البخارية لتوليد الكهرباء - مخبر محطات الطاقة

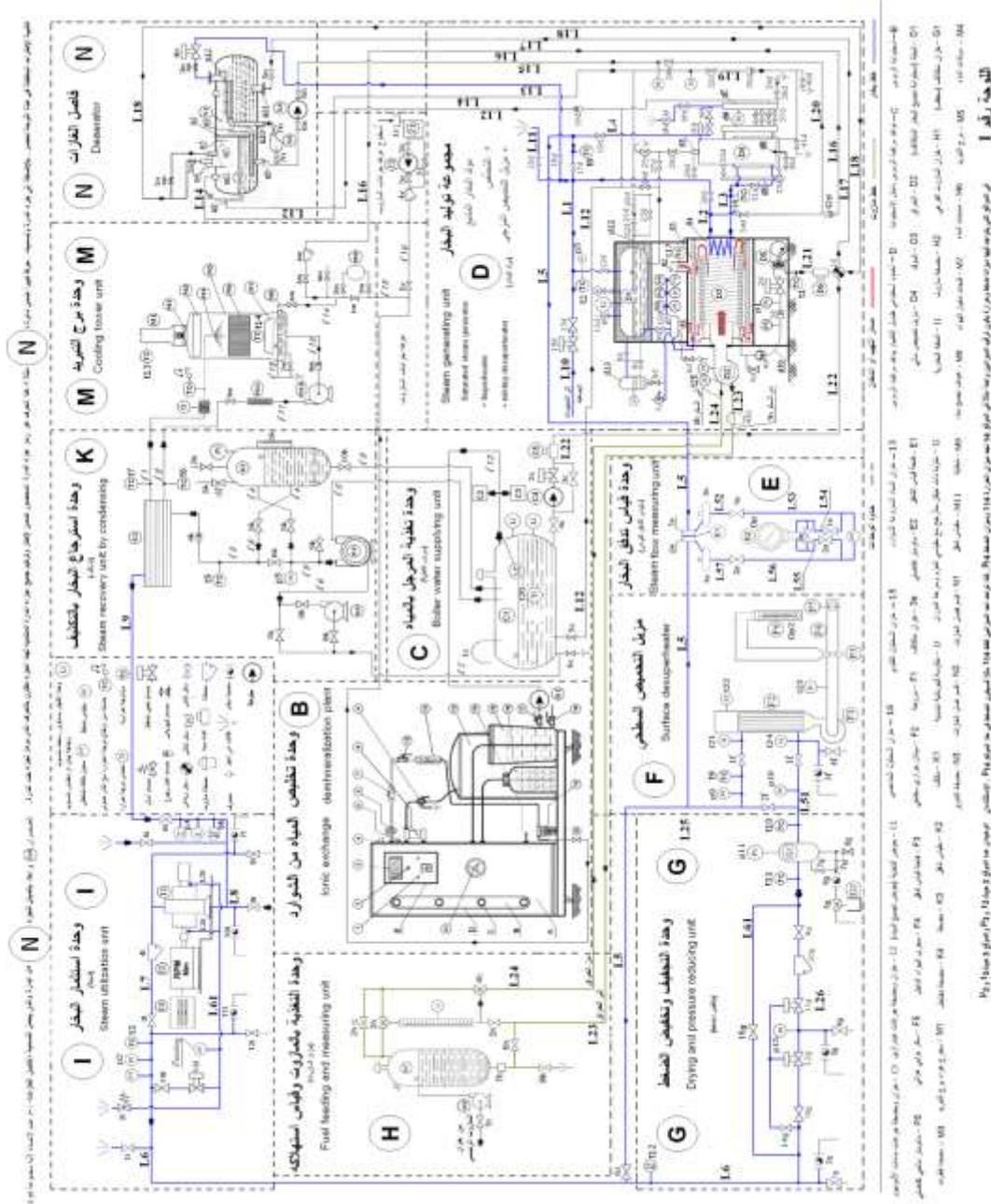


Figure (5) Schematic diagram of steam power plant(Detecta-italia).

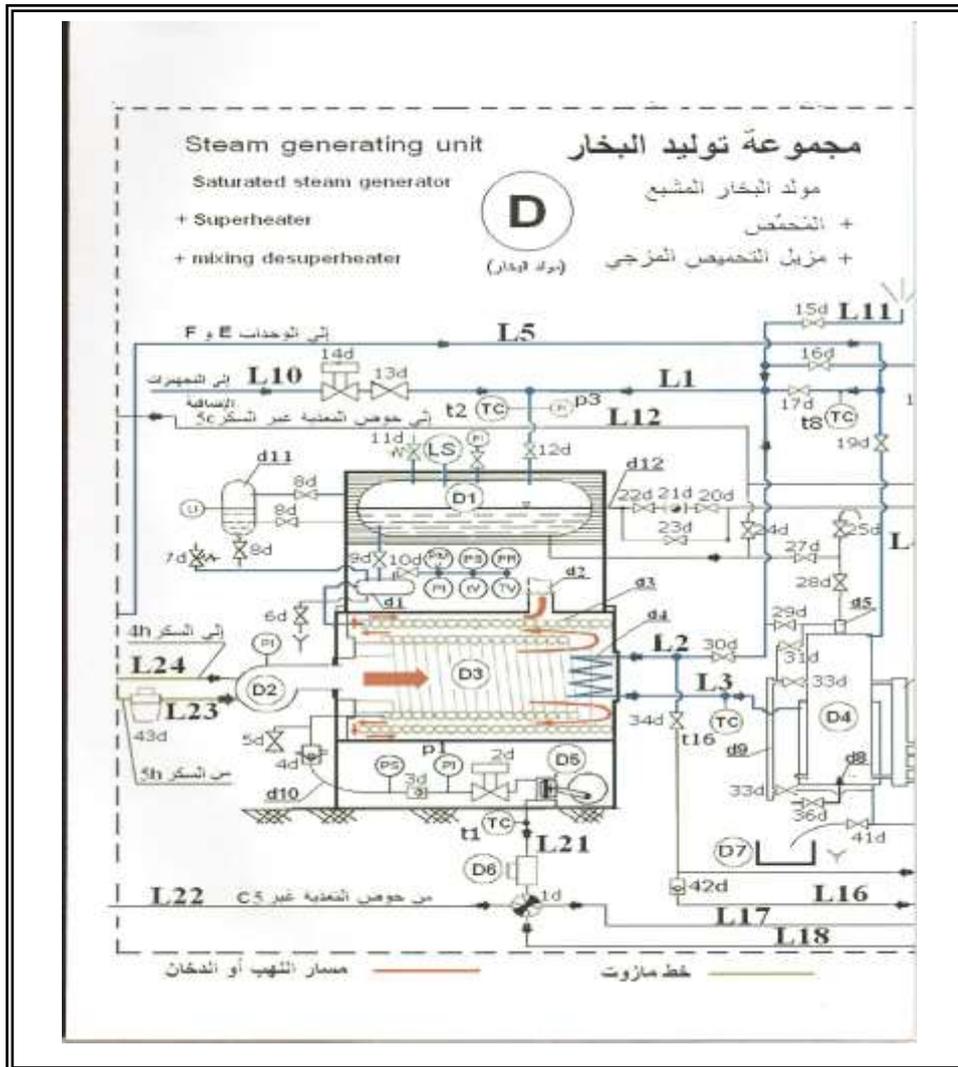


Figure (5-a) a schematic diagram of steam generation unit

D1-drum boiler, D2-burner, D3-furnace, D4 –super heater, D5-circulating pump, d11 - drum level , PS- safety pressure switch, TV -steam thermostat, PI- pressure gage, tv- steam working temperature , ct- water inlet temperature, PR- working pressure regulation , 1d- discharge , 2d- non return valve, 3d- condensate discharge valve , 4d - bleed valve for condensate tank, 5d - by pass line to measure water flow rate to the steam generator, 6d - valve , 7d - heat exchanger,8d- safety valve , 9d- condensate discharge

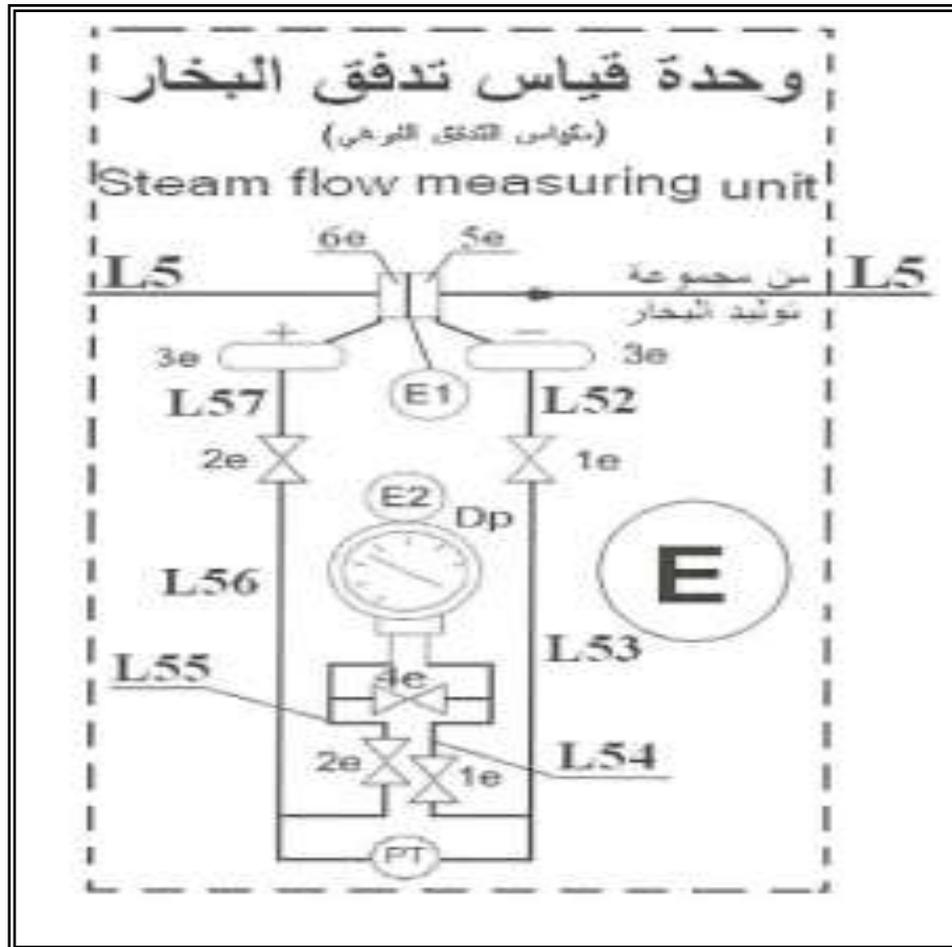
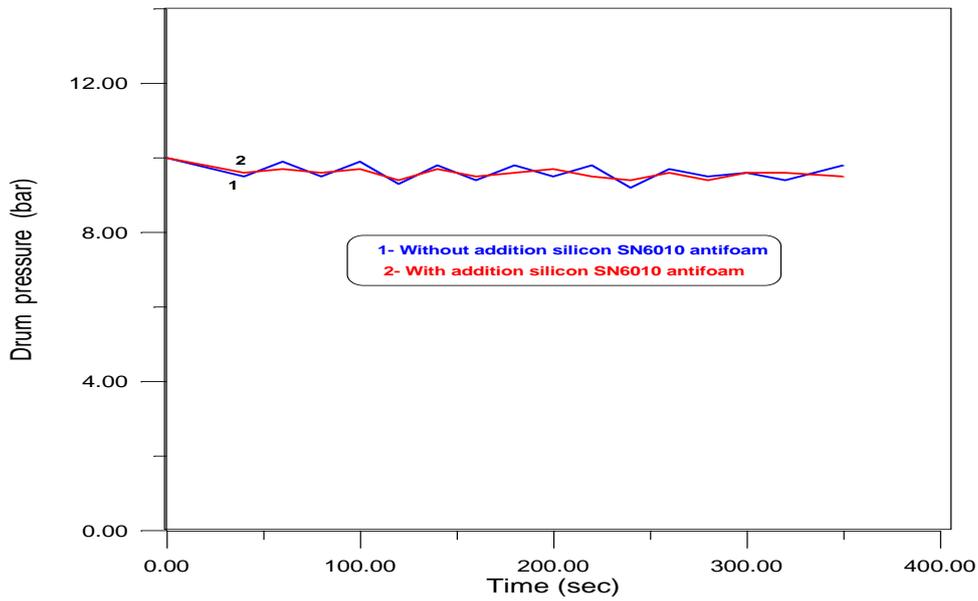
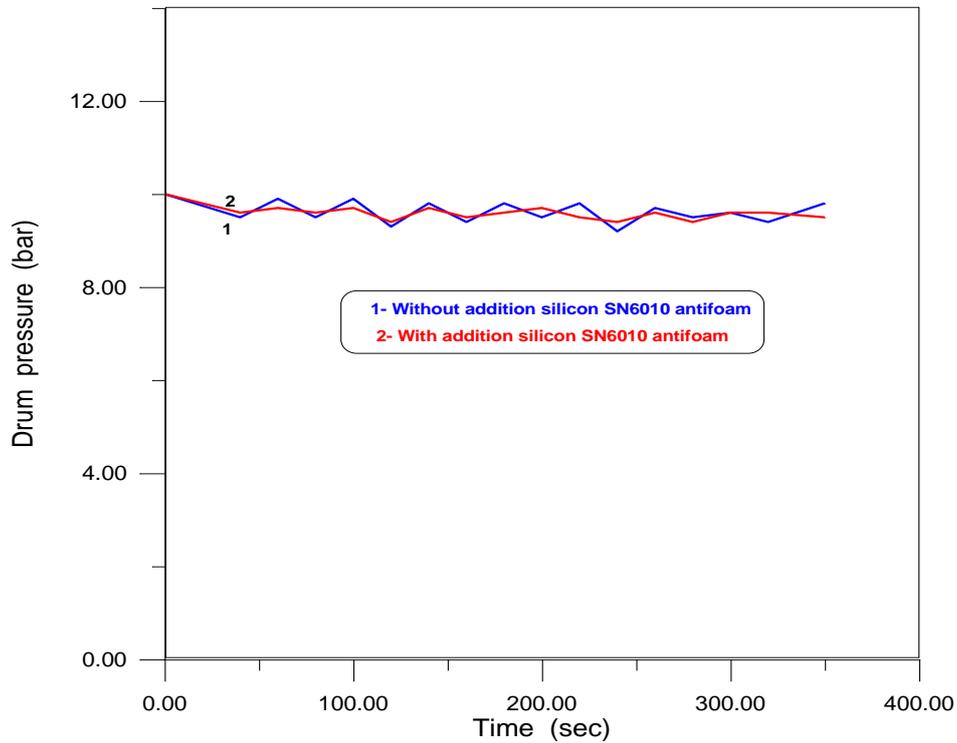


Figure (5-b) a schematic diagram of steam flow measuring unit

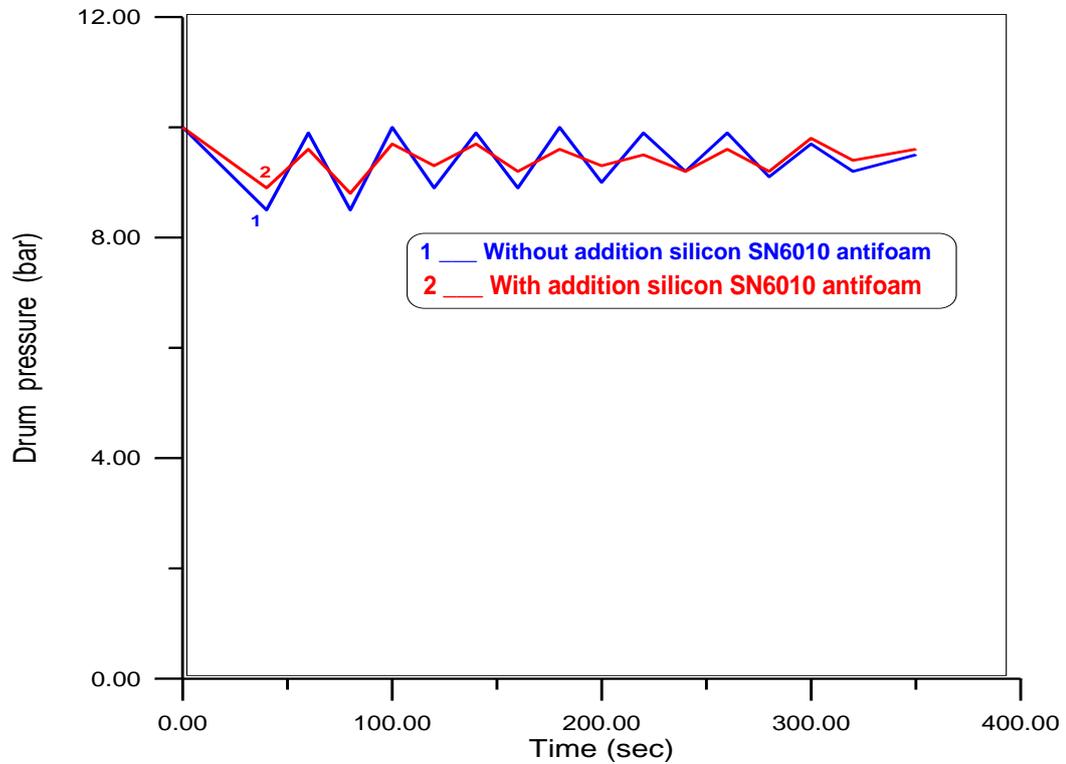
E1 – gauged diaphragm, E2 - differential manometer, 1e – insertion valve of the measurement unit, 2e- 3position selector valves, 3e – condensate reservoir, PT – Pressure transducer



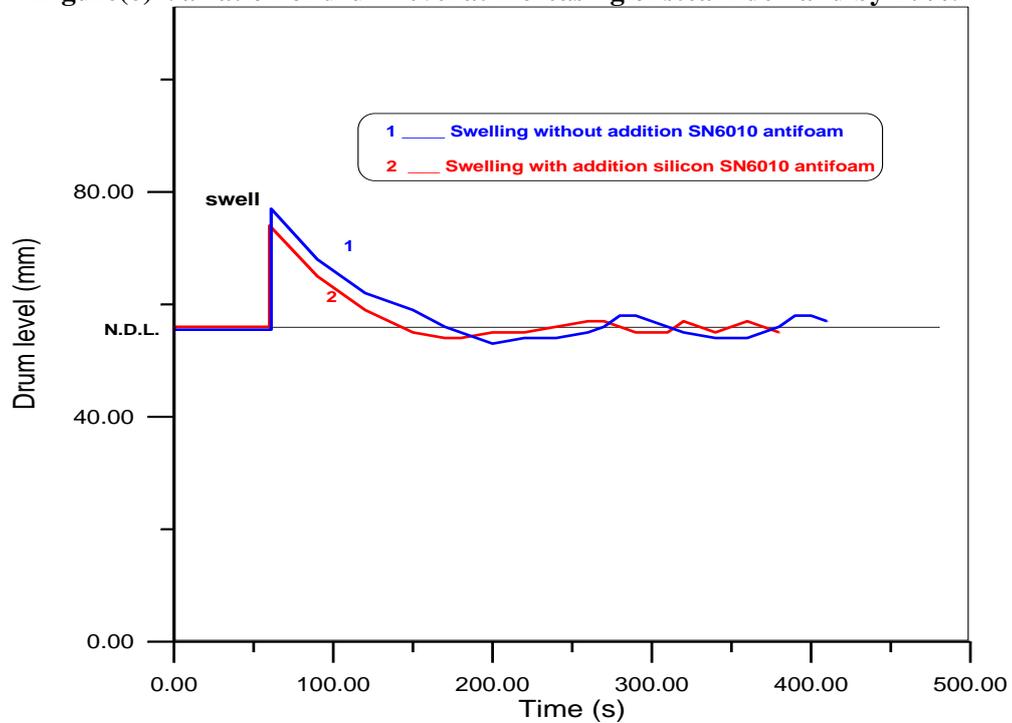
Figure(6) Variation of drum pressure at normal operation.



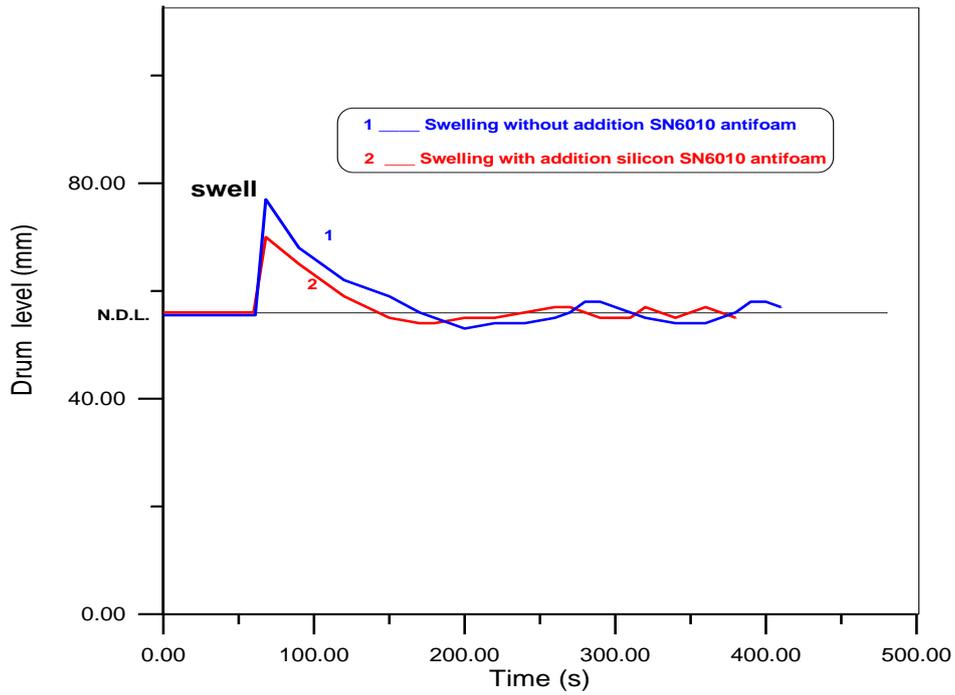
Figure(7) Variation of drum pressure at increasing of steam demand by 10%.



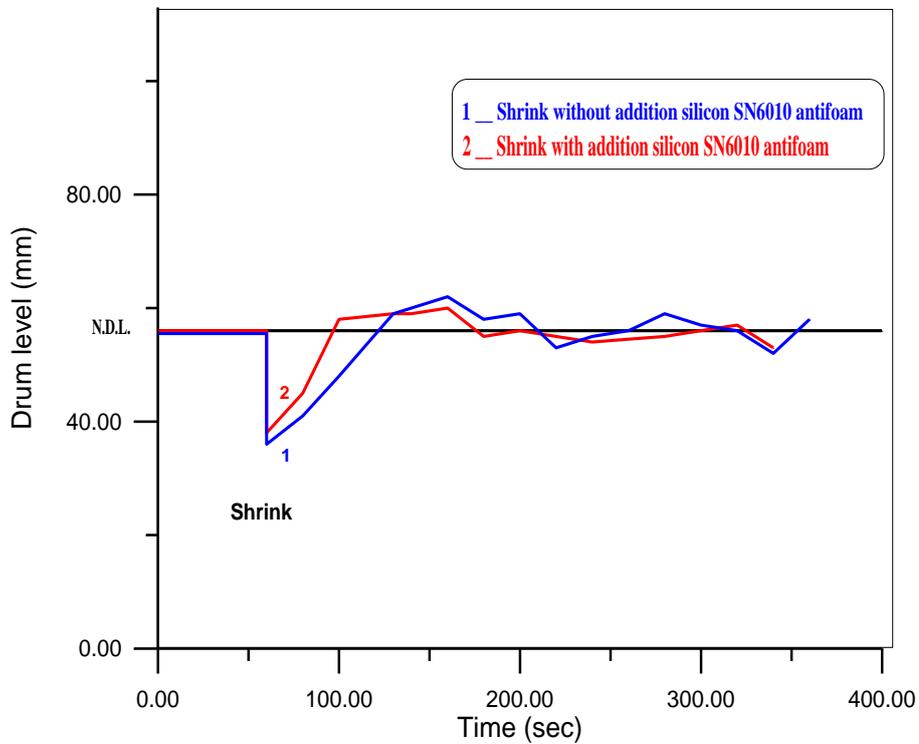
Figure(8) Variation of drum level at increasing of steam demand by 20%.



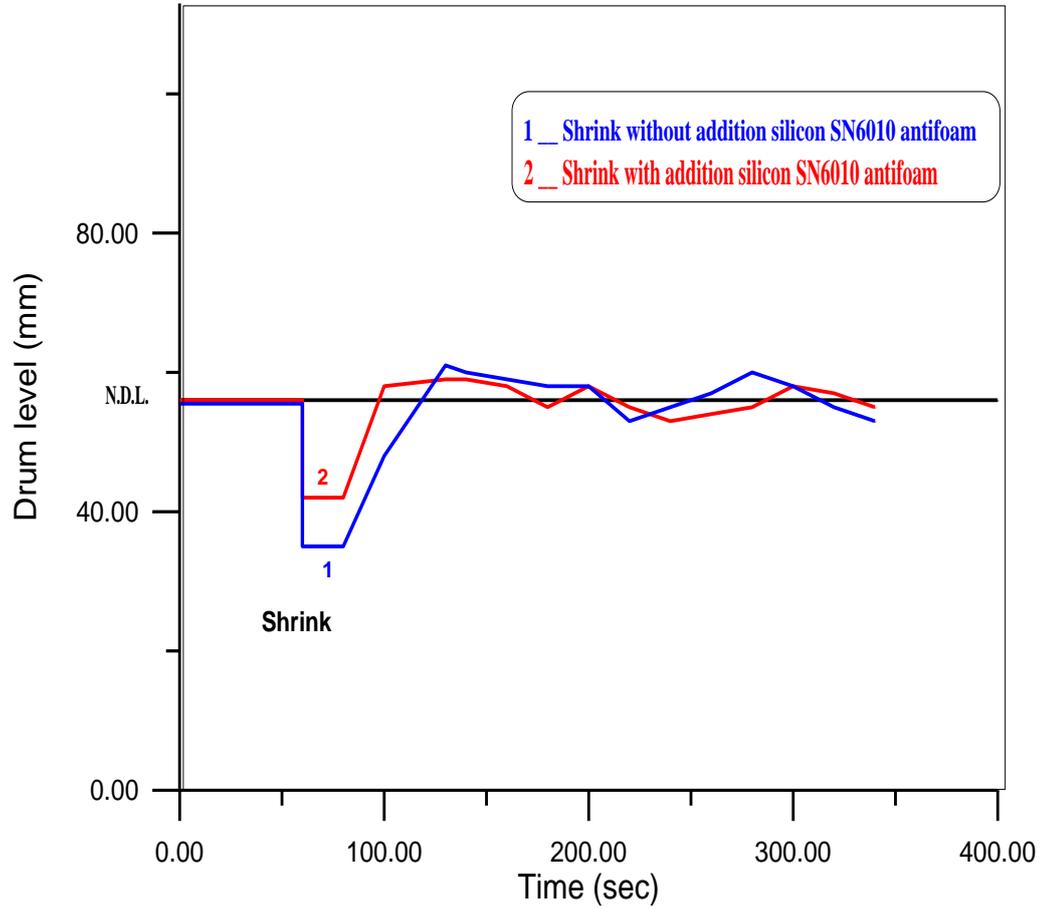
Figure(9) Variation of drum level at increasing of steam demand by 10%.



Figure(10) Variation of drum level at increasing of steam demand by 20%.



Figure(11) Variation of drum level at decreasing steam demand by 10%.



Figure(12) Variation of drum level at decreasing of steam demand by 20%.