

**OPERATIONAL PERFORMANCE OF 2 x 5000 m³/day MSF SIDI KRIR
DESALINATION PLANT
PART I
ENHANCEMENT OF CHEMICAL CLEANING & BRINE HEATER
CONDENSATE PROCESS**

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ABSTRACT

This paper discusses effect of the abnormal seawater carbonates concentration at the 2 x 5000 m³/day Multi Stage Flash (MSF) Sidi Krir desalination unit's site and the variation in scale grade in both (i) Brine Heater and (ii) Evaporator Condensers (water boxes). The negative side effects of combining the two heat transfer components in one acid cleaning circuit are discussed and the approach for separating the cleaning circuits of these two heat transfer components is presented. On the other hand, an indirect Brine Heater heating system; using a separate re-boiler is proposed. The technical and economical advantages of these proposals are highlighted.

Key Words: Desalination, MSF, Performance, Scale, Chemical / Acid Cleaning.

INTRODUCTION

Sidi Krir power plant (2 x 325 MWe), located at the Mediterranean Sea (West coast of Alexandria, Egypt) has a 2 x 5000 m³/day MSF distillation units of brine re-circulation type. Each unit consists of 17 heat recovery stages and 3 heat rejection stages. Heating steam is delivered from the power plant's auxiliary boiler of a reduced pressure of 7-8 bars. More plant design specifications are given in Table (1). Being at the south coast of Mediterranean Sea, Sidi Krir MSF desalination units face a relatively higher sea water salinity and abnormal sea water concentration of carbonates. Such special concentration is mainly due to the geological structure of this coast, which is distinctive with high lime sediments, in addition to the minor effect of tidal and civil activities. Similar water analysis could be expected along the south

Mediterranean Sea and in plants sites as Al Arish (Egypt) and Zilton and Derna (Libya). Table (2) shows the differences in concentrations between standard sea water and measured values at Sidi Krir site. As it known, such water concentration will be a main cause of scale deposits that significantly influences the unit operational performance. The intake system of these plants can not be improved (by conventional pre-treatment processes) and operation staff have to face and deal with this phenomenon and its side effect. This abnormal seawater concentration shows, therefore, its negative impact on the unit performance, specially the rate of acid cleaning required. The first part of this paper discusses effect of such abnormal seawater carbonates concentration on the plant operation. The negative side effects of combining the two heat transfer components in one acid cleaning circuit are discussed and the approach for separating the cleaning circuits of these two heat transfer components is presented.

On the other hand, in Sidi Krir (as most of desalination plants), Brine Heater is supplied with high quality auxiliary steam from the main power plant circuit. A conductivity analyzer is installed in the condensate line to guarantee the high quality condensate return. There is always a possibility of condensate contamination (tubes leaks) with the malfunction of the analyzer. The operation staff may prefer to dump the condensate to sea (through a discharge line) in case of any doubts or irregular performance of the analyzer in order to avoid any disturbances in the power plant condenser if such condensate in returned back to the main plant condenser. The second part of this paper proposes, therefore, an indirect Brine Heater heating system; using a separate re-boiler; is proposed. The technical and economical advantages of these proposals are highlighted.

I- SCALE DEPOSITS & ACID CLEANING

A- Factor Affecting Scale Deposits

Scale deposits on the heating surfaces represent one of the major problems facing the operational performance in MSF distillation units. Dissolved salts such as Calcium Carbonate, Magnesium Chloride, Sodium Chloride and Calcium Sulfate are common seawater salts of different solubility. Presence of other salts often exerts a

strong influence on the solubility. Different factors are considered as prerequisites for scale deposit; i) presence of nucleation sites, ii) dissolved solids reaches its super saturation condition, and iii) reasonable retention time of solution inside the unit. Scale formation is also influenced by solution temperature, pH and fluid velocity (flow turbulence). Smooth heat transfer surface minimizes the presence of nucleation sites for scale deposits and crystallization. Higher flow velocity and enough turbulence (and less presence of stagnant pockets) also reduces scale deposition.

As saline water temperature increase, the solubility of some salts is lowered; hence super saturation is reached and is immediately followed by salt deposits. Solubility – temperature relationship is considered a primary controlling factor for creating super saturation and scale deposit conditions. It has been explained by the inverted solubility curve of the common dissolved solids in the saline water. Generally speaking, scale formation occurs more quickly in the tube sections of the high temperature such as Brine Heater and high temperature stages of the evaporator. Decreasing the system Top Brine Temperature (TBT) could improve the scale deposit situation, however, low TBT negatively influence the system performance and productivity (reduction in the flashing range). Designers have to strike the correct TBT that can technically and economically balance scale deposits, operational performance, capital and running costs.

The formation of alkaline scale (calcium carbonate and magnesium hydroxide) is considered to be a natural phenomenon in sea water distillation plants. High alkalinity (carbonate, bicarbonate and hydroxides) was recorded with such abnormal concentration along the Sidi Krir site coast, as indicated in Table (2). Six kg per cubic meter of hardness (expressed as calcium carbonate) require softening chemicals of almost the same order. For a 2 x 5000 m³/day Sidi Krir (and large capacity) plant(s) this would consume several tons of softening chemicals per day and the cost of pretreatment chemicals and softening will be quite considerable and can not be economically justified. In addition, the pretreatment using Nano filtration has not, yet, proved technically and economically to be the alternative solution.

Another factor influencing the scale deposit is the solution pH. The solubility of calcium carbonate is determined by the solubility product of calcium and carbonate ions; i.e. $c_{Ca} \times c_{CO_3}$. Increasing the solution temperature deposits Calcium Carbonate ($CaCO_3$) from its saturated solution). This situation occurs even if no carbon dioxide is lost and no evaporation takes place. In practice, however, the heating of saline water leads to loss of carbon dioxide from the water which in addition to the progressive increase in concentration (due to evaporation) enhances calcium carbonate deposits.

Scale formation indications are usually observed and monitored by; (i) An increase in brine heater pressure and temperature, (ii) drop in TBT (increase in Brine Heater terminal temperature difference), (iii) Loss of distillate production (the rated distillate output can no longer be maintained under the same steam consumption), (iv) reduction in performance ratio (PR). Different techniques are implemented for scale prevention (or minimization) of Sidi Krir and most of desalination plants including; i) Design the unit temperatures and brine concentrations with minimum opportunity to form salts super-saturation solution before it leaves the unit, ii) partial removal of salts causing scale-formation from saline feed water (intake system) using softening (Ultra and/or Nano Filtration), specially for small units iii) Chemical additives (e.g. acids) which causes a decrease in pH, iv) Anti scalent additives that retards (or delays) scale deposition on heating surface (2.g. polyphosphate, Belgard EV-2000, ...etc), v) Mechanical cleaning (e.g. spongy balls, ...etc) and Chemical (Acid) cleaning to remove precipitated scale during operation., and finally, vi) Scheduled acid cleaning

B- Acid Cleaning

Scheduled acid cleaning process is used to remove accumulated alkaline scale of calcium carbonate ($Ca CO_3$), and magnesium hydroxide ($Mg (OH)_2$) during a specified period of operation. This process is accomplished by circulating a diluted acid solution through the loop to be cleaned. A good monitoring and operation of the scheduled acid cleaning is necessary to maintain a good plant performance and at the same time protect the heat transfer tubes from corrosion. As indicated before, scale formation would be more apparent in the brine heater (and the nearer stages of the

evaporator condenser tubes) due to the higher saline water temperature, leading to reaching super saturation conditions. In addition, the danger of hard scale deposit may also be possible in such high temperature zones that increase the hardship of scale removal (In fact, inspection staff usually notice the presence of such high grade –hard-scale inside the brine heater tubes). In addition, some brine heater tubes blocking is observed, while the low temperature condenser tubes (and water boxes) are clean). These factors should be taken into consideration when acid cleaning process is applied.

A usual plant practice is to test a selective sample in the plant laboratory, in order to detect the minimum active acid concentration that can dissolve the scale (in an acceptable cleaning time) with tube corrosion protection. Table (3) shows a typical acid cleaning test results. The table indicates that the acceptable acid concentration Table (4) summarizes the acid cleaning process specification, while Table (5) summarizes the plant typical acid cleaning process specifications and procedure.

C- Enhancing Acid Cleaning Process

In most of desalination plants, design of acid cleaning circuits combine both (i) brine heater and (ii) evaporator condensers tubes in one integrated circuit. Figure (1) shows the conventional acid cleaning circuit, which incorporates both brine heater and condensers tubes.

Inserting the two heat transfer components in one acid cleaning circuit (same acid dilution and cleaning period) may lead to the deterioration of condenser tubes material which are usually made of lower grade alloy than Brine Heater tubes. Exposing the lower grades (and relatively clean condensers tubes) to the same cleaning process and rates as the (higher grade alloys and highly scaled) brine heater tubes, cause a higher chemical stress on condensers tubes, where a considerable copper ions (Cu^{++}) was recorder (> 5 ppm) although inhibitor is normally added.

A modification in acid cleaning circuit is therefore needed to prevent such chemical stress and maintain high unit performance (performance ratio - PR) and short unit outage (availability factor - AF). The proposed new approach separates the cleaning

circuits of the brine heater and evaporator components as shown in Figure (2). The modification of the original system (compare Figures (1) & (2)) consists only of adding a Tee connection at the ball cleaning line. A few meters (2 m -10 m) 3.0 inches pipe line connects the Tee to the acid cleaning tank with an isolation valve. A blind flange will be installed at the line connecting the B. H. to the evaporator to isolate the B. H. from the evaporator. In this case we can have two circuits operates separately. In case B.H. is only needed to be cleaned, acid flow out from the B.H. will be forced to flow through the Tee to the acid cleaning tang (the blind flange will block the acid flow to the evaporator), as shown in Figure (2). In case both B. H. and evaporator are to be cleaned, the isolation valve is closed the flow is forced to go as normal to the evaporator as shown in Figure (1).

The effect of the proposed approach in enhancing the acid cleaning process, as well as its technical and economical advantages could be obtained from Table (6). The advantages includes; (i) Low chemical consumption, (ii) Shorter outage time, which increases the unit availability and, therefore, production, (iii) protection of water boxes and condensers tubes against chemical stresses, and (iv) improving the performance of ball cleaning system. All these factors lead ultimately to lower water production cost.

II- HEATING STEAM TO BRINE HEATER

As previously indicated, the operation staff may prefer to dump the condensate to sea (through a discharge line) in case of any doubts or irregular performance of the analyzer in order to avoid any disturbances in the condenser if such condensate in returned back to the main plant condenser. In the last year, condensate dumping took place in about 70 % of the plant-operating time. Loss of Brine Heater condensate (600 m³/day) represents about (3000 \$ of water + 1000 \$ of heat = 4000 \$) per day; i.e. 1.0 \$ million per year.

In order to prevent or reduce such water and heat cost loss, an indirect Brine Heater heating steam system; using a separate re-boiler, is proposed. The proposed system would provide the B.H. with the required steam where its condensate is contained in a closed loop, separate from the main power plant steam. As conventional re-boilers

used in the plant, auxiliary steam from the power plant will be used as a source of heat for the re-boiler. Figure (3) illustrates typical re-boilers used in Sidi Krir plant to provide 5.0 bars, 160°C saturated steam for different processes as (i) Mazout storage and transfer heaters, (ii) burners fuel heaters, and (iii) heat tracing piping steam.

Figure (4) illustrates the proposed re-boiler circuit for B. H. steam supply. For new plants, this circuit could be replaced by the proposed separate re-boilers system, as shown in Figure (5) or integrated with the re-boilers for other plant processes. Due to the location limitation in Sidi Krir, the circuit would be built separately and as near to the desalination units as possible. Similar to the other re-boilers circuits, the system will be designed to provide the B. H. with the required saturated steam at 7.0 bars, 205°C and 600 m³/day. Condensate from B. H. would be collected in the re-boiler condensate collection tank and (or directly) forwarded to the re-boiler feed tank by the re-boiler condensate transfer pump(s) (In the conventional re-boiler system, the unit condensate transfer pumps supply any shortfall in condensate tank requirements, in order to maintain the condensate level, through a level control system). Condensate is then pumped back to the re-boiler. The same auxiliary steam at 15 bar (g) and 275°C is supplied with the required flow rate to the new re-boiler as its heat source. The steam is then de-superheated to 213°C by a desuper heating system before it enters the tube side of the re-boiler. The auxiliary steam is condensed and the condensate is collected in the drain tank, Figure (5), then transferred to the main circuit by pressurizing the drain tank with the auxiliary steam (from the auxiliary steam header).

Table (6) summarizes the expected capital cost of the re-boiler system, while Table (7) summarizes the running cost and the pay back period of the newly proposed system. From these tables, it seems that the proposed system is economically feasible and its pay back period is only 7-8 months. This adds to the technical advantages of the proposed B. H. heating system of either (i) protecting the main power plant water quality or (ii) water and energy loss of dumping B.H condensate to the sea.

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**Table (1) Technical Specifications of Sidi Krir
2 x 5000 m³/day MSF Desalination Plant**

Parameter	Value (Remark)
No. of Units	2
Unit Capacity	5000 m ³ /day
No. of Stages	20 (17 + 3)
Designed PR	8 kg (PW) / kg (steam)
TBT	110°C
Seawater Temp.	27°C
Heating Steam Temp.	117°C
Cooling Water Flow Rate	1570 m ³ /hr
Brine Recirculation Flow Rate	1850 m ³ /hr
Seawater Concentration	43900 ppm
Brine Concentration	63000 ppm
PW Quality	25 ppm
Method of Scale Control	High Temp. Additives (Belgard EV 2000)
Tube Sheet Material (BH + Condensers)	90 / 10 Cooper Nickel
Condensers Tubes	90 / 10 Cooper Nickel
Brine Heater Tubes	70 / 30 Cooper Nickel
Water Box (BH + Condensers)	90 / 10 Cooper Nickel

Table (2) Sidi Krir Site Sea Water Concentration

Item	Site	Standard	Difference (%)
Na Cl	23000	23476	- 476 (- 2 %)
Mg Cl	5800	4981	819 (16.4 %)
Na ₂ SO ₄	4420	3917	503 (12.8 %)
Ca Cl ₂	1260	1102	158 (14.3 %)
K Cl	800	664	136 (20.5 %)
Alkalinity (Ca CO ₃)	290	192	98 (51 %)
TDS	43,900	34,480	9,420 (27.3 %)

Table (3) Acid Cleaning Laboratory Test Results

Sample Weight (gm)	2.5	2.5	2.5	2.5	2.5
Acid Solution Volume (mL)	100	100	100	100	100
Acid Solution %	0.5	1.0	1.5	2.0	2.5
Duration Time (Hr)	12	12	12	12	12
pH (Strat)	1.1	0.85	0.3	0.15	<0.1
PH (Final)	1.8	1.4	0.85	0.4	0.15
Solubility (%)	10	10	100	100	100

Table (4) Specification & Procedure of Acid Cleaning Process

<p>Specifications Circuit Volume = 67 m³ Concentration of Acid Cleaning Solution = 1.5 % Concentration of Inhibitor Circuit = 0.2 % Recirculation Max. Duration Time = 24 hours</p>
<p>Procedure</p> <ul style="list-style-type: none"> - Unit shut down and cool down - Investigate of scale formation in condensers and take samples and photos - Prepare acid concentration required and the acid cleaning circuit - Recirculate the acid solution through the cleaning circuit for the specified period - Monitor the circuit main parameters (pH, HCl, T.H., Cu+, ...) during the cleaning process till a constant values are obtained (at the end of the cleaning process, pH should be less than 1.0 to indicate active acid can react with more scale) - Neutralization and drain the circuit - Perform post cleaning inspection

Table (5) Comparison Between Present and Modified Acid Cleaning Circuits

Item	Present	Modified
Circuit Volume (m ³)	67	8
Acid Consumption (Liters) (37 % Concentration)	3 000	400
Inhibitor Consumption (Liter)	150	20
Neutralization Caustic Soda (Lit) (50 % Concentration)	1500	200
Outage Time (Days)	3	1
Chemicals Cost (USD), (1)	1,250	220
Cost of PW Loss During Cleaning (USD), (2)	18,000	6000
Total Cost (1) + (2)	19,250	6220

Table (6) Estimating Capital Cost of Sidi Krir Reboiler System

Item	Cost (\$)
Aux. Reboiler Heater (A,B)	365,859
Feed + Condensate Pumps (A,B)	35,220
Drain + Feed Tanks	123,562
Furnishing Pipes + Insulation	20,000
Furnishing Equipment	61,000
Total	605,641
Pay Back Period = Total Cost / Annual saving = 605,641 / 1000,000	7 – 8 months

Table(7) Reboiler System Running Cost

Item	Cost (\$)
Pumps Power (Feed =24 kW, Condensate=10 kW) = (24+10) kW x 24 hrs/ day x 365 day/year x 0.02 \$/kWhrs)	5,957
Capital Installment (Annuity) = 605,641 [(1+.06) ²⁵] / 25	77,695
Total	83,652

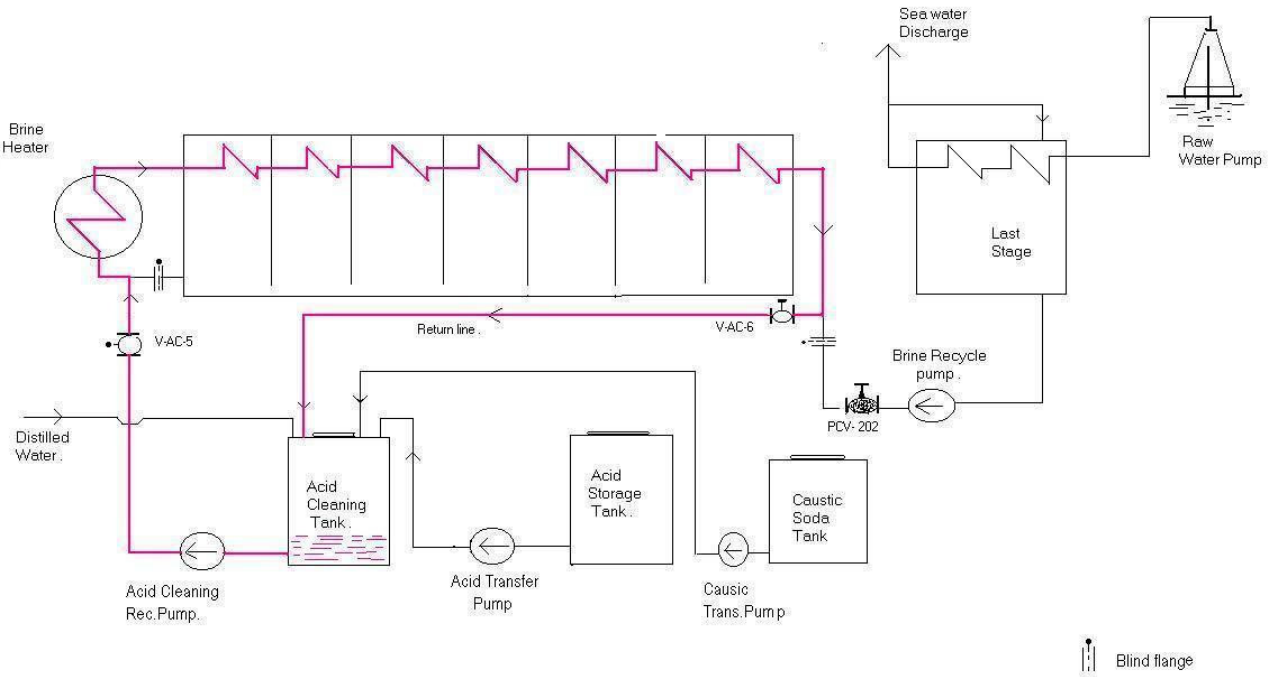


Figure (1) Conventional Complete Circuit (Brine Heater+Condensers)

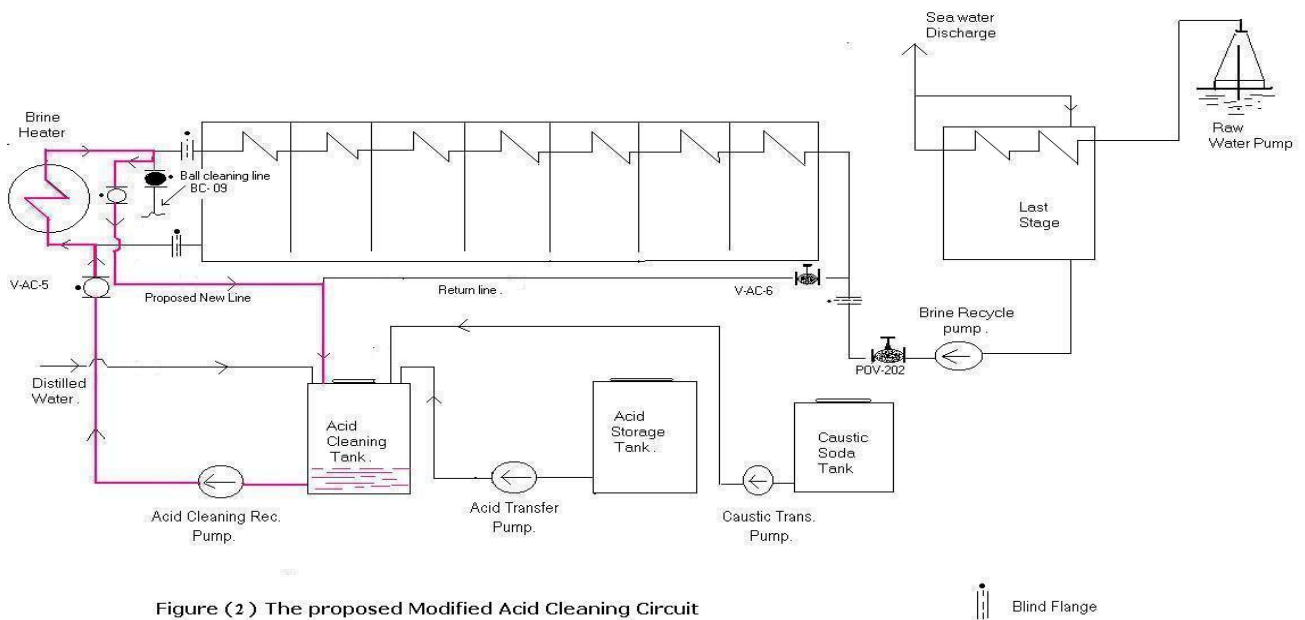
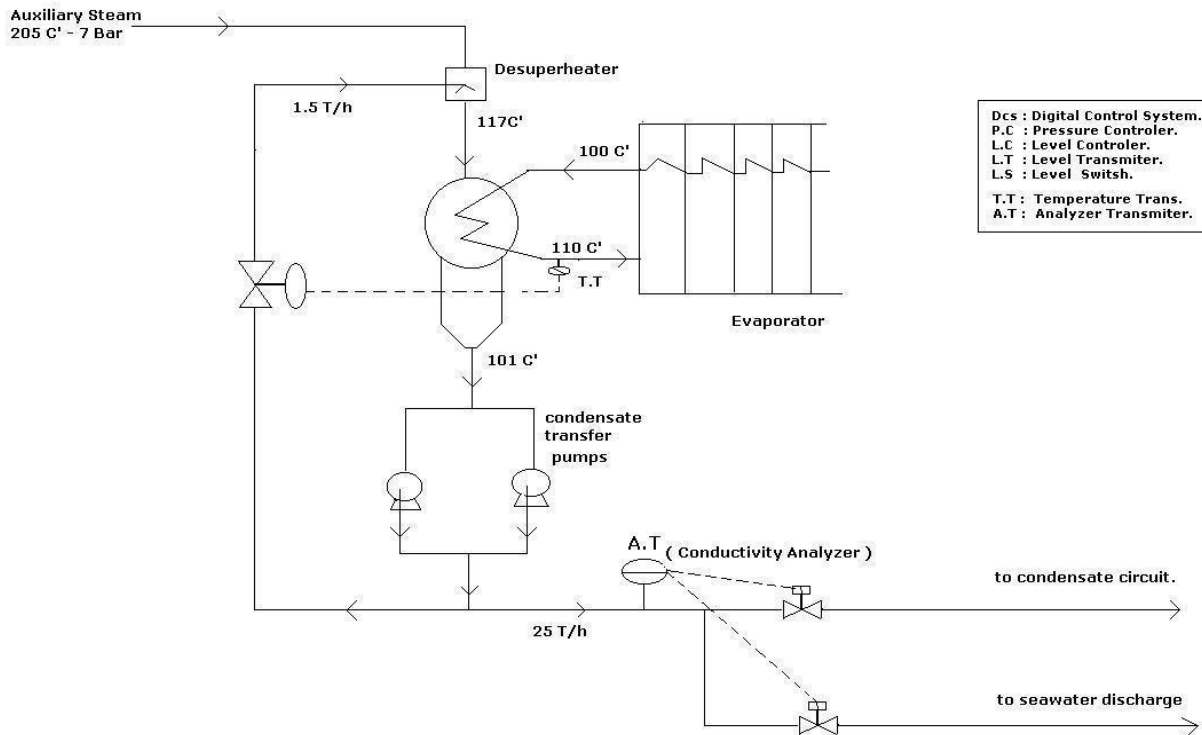
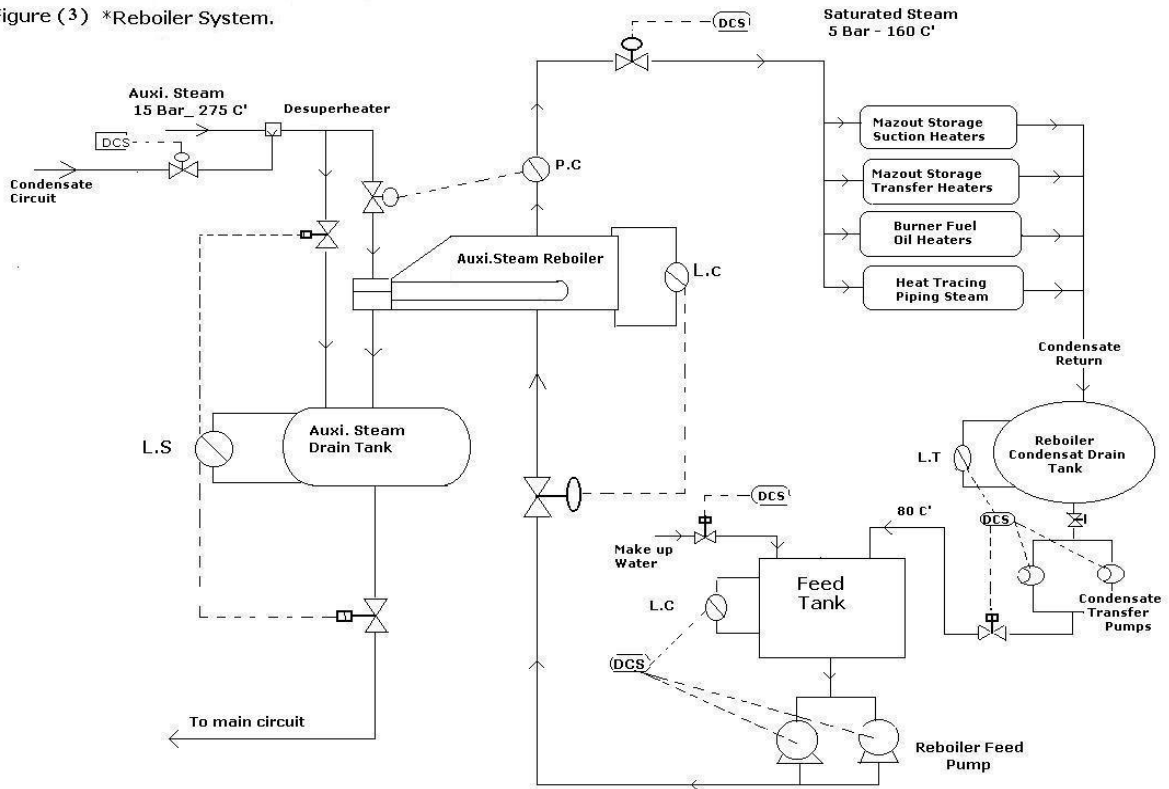


Figure (2) The proposed Modified Acid Cleaning Circuit

Figure (3) *Reboiler System.



DCS : Digital Control System.
 P.C : Pressure Controller.
 L.C : Level Controller.
 L.T : Level Transmitter.
 L.S : Level Switch.
 T.T : Temperature Trans.
 A.T : Analyzer Transmitter.

Figure (4) *Brine Heater And Its Condensate System

Figure(5)

*Combined system
Reboiler system- Desal. System

