A novel double distilled water plant: Fully automatic without automation

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A novel double distilled water plant has been designed and fabricated with the main objectives to overcome the drawbacks of existing conventional plants and to save energy. The detailed schematic drawing of the plant is given; its operating procedure is also discussed. Its working is based on a non-conventional method of vaporizing water. All the aspects of the experimental observations and results are discussed thoroughly. The rate of distillation is observed to increase with rise in the cumulative volume of the distillate. The proposed plant has got versatile applications. Single distilled water can be produced from the same unit. Good quality pyrogen free distilled water is obtained.

Double distilled water is used for precise analysis in educational, medical, biochemical, environmental and industrial laboratories. It is also used in large quantities for infusion of drugs in the body of patients in hospitals. In conventional distilled water plants, heating filaments embedded in either metallic or ceramic casings are used which offer resistance to heat transfer from the hot filament to water. Further, heat transfer is reduced due to the insulating effect of scales formed over the covering of the filaments during use. These factors result in higher energy consumption and the efficiency of the plant also goes down. A more serious drawback in addition to the wastage of energy is the over-heating of the filaments caused by one or the other reasons, e.g., dry heating of the filaments in case of the failure of water supply, higher voltage supply and excessive scaling on the covering of the filaments which reduce the life of the filaments. Very often, replacement of the filaments is required. Further, two separate heaters are used in the conventional units for the production of double distilled water. Failure of either one of the heaters stops production of double distilled water. Automatic distilled water plant needs extra cost of automation. Heaters burn-out is frequently observed even in case of automatic distillers.

The present distillation device not only overcomes these problems and deficiencies of the conventional units but also possesses a number of other exceptional features, as discussed in the paper. The present work is an extension of the author's earlier work on a novel single distilled water plant. The literature records no such other work. The quartz double distiller, patented by M/S Bhanu Scientific Instrument Company using heating filament as a source of heat, is quite different than the one used in the present plant.

Experimental Procedure
Experimental set-up — The detailed schematic diagram of the distillation plant fabricated from corning glass is shown in Fig. 1. The plant consists of
a single piece of two coaxial cylindrical stills of 4 L.
(S1) and 3 L. (S2) of net holding capacities and a
flanged lid with ground joints for fitting a top con-
denser (C1) and a pair of vertical electrodes (E1). Two
parallel horizontal electrodes (E2) are placed at the
bottom of the outer still (S3). For visualization they
are shown on the same horizontal axis. The electrodes
are made-up of stainless steel sieve and fitted to the
stills through teflon corks (B). Both pairs of elec-
 trodes are connected in parallel to the mains via a
voltmeter (V), an ammeter (A) and a wattmeter (W).
A fuse cut-out is provided for safety. A glass tube
fitted with a thermometer (T) is provided to measure
the temperature of the first distillate running down
from the condenser (C1) to the still (S3). This tube is
fixed to the condenser and the still with the help of
ball and cup joints. Provisions for feed water with
overflow (F) and for condensing double distillate in a
side condenser (C2) are made as shown in the figure.
Water level in the still can be adjusted to any desired
position by adjusting the vertical placement of the
feeding funnel connected with polythene tubing to the
drainage pipe (I). The change in the water level in the
still causes change in the active area of the electrodes
and hence, the rate of distillation can be varied easily
to the desired level. Proper insulation (H) of thermo-
cole and coaxial arrangement of the stills in a single
closed system prevent heat losses, and increases
the thermal efficiency of the device thereby. Drainage
plug (I) is provided at the bottom for partial cleaning
of the still (S1).

Method — The plant works on the principle of
the heat generated due to the resistance offered by water
through which the electric current flows between the
electrodes. A few minutes after the power is switched
on, water in the stills starts boiling and first distillate
starts coming out from the top condenser flowing
down to the still (S3) containing already a distilled
water solution of potassium permanganate (250
mg/L). Addition of potassium permanganate solution
in the beginning is essential to make first distillate
conducting. No further addition of potassium permanganate
is required. The vapors produced in the still
(S3) condense in the condenser (C2) to give double
distilled water. Water equivalent to the distillate is fed
automatically in the still (S1) through feeding funnel
connected to the condensers in series. The excess
amount of water flows out of the over-flow port of the
feeding funnel and goes to sink, and thus, the water
level in the still (S1) remains constant.

The concentration of salts in water in the still (S1)
increases due to continuous distillation and conse-
quently, the electrical current increases through the
electrodes (E1) resulting in a rise in the rate of first
distillation. The variation in the rate of first distillate
which enters still (S2), causes change in the level of the
water and the active area of the electrodes (E2),
consequently the rate of double distillate also varies.
Hence, a true steady state condition can’t be achieved
before saturation of salts in the still (S1). But, for all
practical purposes, readings recorded in very short
duration of about 5 min can be taken as under pseudo-
steady-state conditions (PSSC). The water level in the
still (S1) is adjusted and the readings regarding the
rate of distillation, cumulative volume of distillate
collected, energy consumed, voltage applied, current
passing and the time elapsed are recorded under
PSSC. Data are presented in Fig. 2. Constant voltage
is maintained with the help of an autotransformer.

For better heat recovery, the temperature of the
first distillate entering the still (S2) should be above
90°C and that of the feed water entering still (S1)
should be above 70°C. This can be achieved by pro-
viding sufficient condensing area and by controlling
the flow rate of cooling water. To avoid excessive
deposition of solids on the electrodes as their concen-
tration increases with distillation in still (S1) and be on
the safer side (as the current also increases), it is ad-
visable to flush-out a part the contents of the still after

Fig. 2 — Characteristic curves for the novel double distiller
every 15 L of distillation or when the current reaches 14 A, by lowering the feeding funnel to sink. The funnel should be brought back to its original position to allow tap water to enter the still and in this way distillation cycle can be repeated several times.

For overnight operation, the initial rate is adjusted by manipulating the level of water in the still (S₁) such that about 15 L of water is distilled during the night. Next morning the distillation cycle, as mentioned, can be repeated, if needed. By opening drainage plug (I), bigger solid particles collected at the bottom can be removed with the help of a brush when the unit is shut-off. In this way, the device can be made capable of working continuously without any interruption in the production of distilled water for many months. After about every 1000 L of distillation, the lid should be opened and the wall of the still be cleaned off the scaling. The hard scaling on the electrodes can be removed with the help of a knife. There is practically no deposition of solids on the electrodes (E₂). Hence, cleaning of still (S₂) is not required. The life of the electrodes is very long as in the present case, no need is felt to change these even after the production of more than 5000 L of the double distillate. The electrodes are easily replaceable.

Even in the event of the failure of water supply, the water in the stills vaporizes and the electrodes remain intact and safe. On resumption of water supply, the plant starts working automatically. A solenoid valve (X) can be used to automatically regulate the supply of water used for cooling in the condensers and boiling in the stills so that the wastage of the water can be avoided in the case of the failure of power supply. The same plant can be used for the production of single distilled water by collecting the first distillate from the condenser (C₁). The still (S₁) can be used as a re-boiler for separation of liquid mixture kept in the still (S₂) with boiling point of one of the components less than 100°C at atmospheric pressure.

Results and Discussion
When the plant is switched on, temperature of the still (S₁) increases from the room temperature to the boiling point of water within a few minutes. Current also increases to the maximum value and then drops sharply to a lower value on commencement of boiling. Further, a slow drop to the minimum value followed by gradual increase in the current with continuous distillation is observed (Fig. 2) within the safe operational limit. This behavior can be explained as follows: Tap water contains a number of dissolved salts mostly comprising of carbonates, bicarbonates, sulfates and chlorides of calcium, magnesium, sodium and potassium, and shows conductance due to the presence of the ions of these salts. The mobility of the ions (conductivity) increases as the temperature of the water increases causing rise in the current initially. When water starts boiling, most of the bicarbonates responsible for temporary hardness of water are decomposed to less soluble carbonates decreasing the concentration of ions in the water. Also, some portion of the electrodes is covered by the issuing steam bubbles decreasing the active area of the electrodes; consequently, a steep fall in the current is observed on commencement of boiling. On continuous boiling, remaining bicarbonates in the still decompose as being not an instantaneous process, causing a further low rate of decrease in the current to reach the minimum value. To substantiate the statements, an experiment was performed to observe the variation of conductivity and temperature of water with respect to the time. The results presented in Fig. 3 are in perfect agreement with the given reasoning.

Water containing impurities is fed continuously into the still and distilled water in the form of steam is removed and thus, the impurities are left behind. As a result, the concentration of ions causing permanent hardness such as sulfates and chlorides of calcium and magnesium along with the other soluble salts increases towards their respective saturation values. Therefore, a linear increase in the current with increasing cumulative volume of distillate produced is observed (Fig. 2), within the experimental limits. The precipitation of dissolved salts causing permanent hardness begins beyond their respective saturation values and it results in the deposition in addition to the decomposed salts causing temporary hardness on
the electrodes (E₁) and the wall of the still (S₁). The solubility data of some of the salts dissolved in the tap water are given in Table 1. It can be seen from the table that solubility of the salts increases with temperature except sulfate of calcium and sodium. It has never been tried to reach saturation because of the safety limitation of the current. Therefore, scaling is mostly caused by the decomposition of salts causing temporary hardness along with few salts responsible for permanent hardness whose solubility is very low at boiling point of water. Gradually more and more salts are deposited producing a thick layer of scale.

It is observed that the layer of scale on the electrodes is very hard while that on the wall of the still is quite soft. The salts deposited on the electrodes are conducting and hence, the electric current passes through scaled electrodes easily. Therefore, care has been taken during designing of the plant to keep sufficient gaps between the electrodes as well as electrodes and wall of the still. Also, the electrodes (E₁) are positioned vertically to avoid short-circuiting due to bridging of the electrodes or touching the scaled wall of the still. Vertical positioning of electrodes have other benefits like, changing the rate of distillation by changing water level in the still and easy cleaning of the still.

As the current increases with continuous distillation, the rate of distillation also increases. It can be seen from the characteristic curves for the double distilled water plant (Fig. 2) that at 220 V, an increase in the current from 3.6 to 14.0 A, increases the rate of distillation from 0.5 to 2.0 L/h and the corresponding power requirement increases from 0.8 to 3.0 kW. Fig. 2 also shows that 18 L of the distillate is produced starting with the initial minimum current of 2.5 A at room temperature which increases to 7.0 A at boiling point and then drops suddenly to a minimum value of 4.0 A on commencement of boiling. Further, gradual increase in current reaches to 14.0 A in about 14 h of continuous operation.

A comparative study shows that the present plant for producing double distilled water is more efficient than a conventional type having two separate heating filaments. The conventional plant consumes 2.0 kWh energy/L for the production of double distilled water whereas; this value is 1.5 kWh for the novel plant. The distilled water produced by the present model in the laboratory (prototype) is of appropriate quality as shown in Table 2.

The quality of distilled water is pyrogen free and free of heavy metals. Comparing the values of pH, conductivity, and dissolved solids corresponding to the single distillate, double distillate and tap water, it becomes obvious that the performance of the device is very satisfactory.

The performance of such a distillation plant depends on the concentration of dissolved solids in the tap water. The concentration of dissolved solids in underground water supplied in our university varies according to the seasons. It has been found maximum (510 mg/L) at the end of summer and minimum (380 mg/L) at the end of rainy season.

It has been observed that if the plant fails just after commencement of boiling of water and the unit remain closed for sufficient long time so that the water in the still gets cooled, then on resumption of power, the time taken for boiling in the still (S₁) is more than twice the time taken to boil fresh tap water in the beginning. This is because the boiled water contains lesser amount of ions (due to decomposition of bicarbonates) than fresh tap water. The conductivity of fresh tap water at 30°C is 2.7x10⁻³ S/cm, while

### Table 1 — Solubility of some of the salts dissolved in the tap water

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Solubility (°C)</th>
<th>Solubility (100°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium carbonate</td>
<td>0.0014</td>
<td>0.002</td>
</tr>
<tr>
<td>Magnesium carbonate</td>
<td>0.011</td>
<td></td>
</tr>
<tr>
<td>Calcium chloride</td>
<td>59.5</td>
<td>347.0</td>
</tr>
<tr>
<td>Magnesium chloride</td>
<td>52.8</td>
<td>73.0</td>
</tr>
<tr>
<td>Calcium sulfate</td>
<td>0.298</td>
<td>0.162</td>
</tr>
<tr>
<td>Magnesium sulfate</td>
<td>26.9</td>
<td>68.3</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>35.7</td>
<td>39.8</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>27.6</td>
<td>56.7</td>
</tr>
<tr>
<td>Sodium sulfate</td>
<td>48.8</td>
<td>42.5</td>
</tr>
<tr>
<td>Potassium sulfate</td>
<td>7.4</td>
<td>24.1</td>
</tr>
</tbody>
</table>

### Table 2 — Specific parameters regarding the novel device and the distillate produced

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tap water</th>
<th>Single distillate</th>
<th>Double distillate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (L/h)</td>
<td>—</td>
<td>0.5-3.0</td>
<td>0.5-2.0</td>
</tr>
<tr>
<td>Power required (kW)</td>
<td>—</td>
<td>0.4-2.2</td>
<td>0.8-3.0</td>
</tr>
<tr>
<td>pH</td>
<td>7.76</td>
<td>6.79</td>
<td>6.94</td>
</tr>
<tr>
<td>Conductivity at 30°C (S/cm)</td>
<td>2.7x10⁻³</td>
<td>4.3x10⁻³</td>
<td>1.4x10⁻³</td>
</tr>
<tr>
<td>Dissolved solids (mg/L)</td>
<td>400</td>
<td>Zero</td>
<td>Zero</td>
</tr>
</tbody>
</table>
it is $1.6 \times 10^{-4}$ S/cm of boiled, filtered and cooled water.

Fig. 4 shows the variation of current during continuous distillation with intermittent partial drainage of the content of still (S1). About 6.5 L of double distilled water is produced starting with boiling current of 9.0 A reaching 14.0 A during a cycle of 4 h operation.

Partial drainage is suggested because of the following objectives: (1) To avoid excessive deposition of solids — As scaling is mainly due to the decomposed bicarbonate salts, partial drainage followed by feed of tap water in the still means presence of lesser amount of bicarbonates in comparison to total replacement of still water by tap water; (2) To remain within the safe limit of current — Rise in current is caused by increase in the concentration of soluble salts of sulfates and chlorides. Solubilities of these salts are very high and current corresponding to the saturated solution at boiling point may be beyond the limit of safety. Partial replacement of still water by tap water decreases the concentration of these salts, thereby lowering the current to remain within the safe limit; (3) To make distillation almost continuous — It takes some time with total fresh feed of tap water to start boiling. Partial drainage followed by feed of tap water starts boiling immediately as the remaining content is hot itself and it takes some time to reach the constant level in the still; and (4) To distill at higher rate — Following the procedure, the variation of concentration of soluble salts occurs within a narrow range of higher values resulting in higher average rate of distillation.

Conclusions

The proposed new double distilled water plant is free from the drawbacks of conventional plants and is more energy efficient. Some of the exceptional features of the new device are: Fully automatic but without any automation contrivance; Free from costly heating filaments and frequent replacement; Free from any risk of dry heating of filaments on failure of water supply; Flexible in use and convenient to operate; Capable of producing single as well as double distilled water; Capable of working satisfactorily even under wide range of voltage fluctuations from 50-300 V ac supply without any risk of damage; Capable of producing distilled water unattended day and night; Controlling the rate of distilled water production within the specified range of 2 L/h; Practically free from maintenance; Easy-to-fabricate locally with the help of a glass blower; No risk of contamination of the distillate at the transfer from the first to the second stage because of the simultaneous and continuous working of the two distillation stages; Thermal efficiency (94%) based on theoretical power requirement: Great benefits to the pharmaceutical laboratories and industries. The plant can be fruitfully utilized in research, educational, pathological, environmental, and any other such laboratories. Also, the stainless steel distiller after fitting with safety valve, pressure gauge and delivery valve could be used as a boiler/re-boiler for various uses such as steam distillation of essential oils.

The performance of the device is quite satisfactory. It has been catering to the needs of distilled water to all the laboratories of our department.

References