7. COST CALCULATIONS USING BITTERS AS FEED.
Cost Calculations using 'Bitterns' as Feed:

The feed used for the electrolysis cells during the present investigation has been obtained from 'Bitterns' which is the mother liquor left after the salt manufacture from the sea water by solar evaporation and is found to be enriched in the D₂O content. Calculations have been made to find the percentage reduction in the cost of production of heavy water that can be achieved by using 'Bitterns' as a source of feed water rather than normal water as feed. For such calculations three formulae, developed by different authors have been used and the results compared.

During all these calculations, it has been assumed that the cost of obtaining water from 'Bitterns' is nil. This is particularly true because of the fact that during the process of separation of water from 'Bitterns', valuable salts like KCl, MgCl₂ and MgSO₄, etc., are also automatically available and can be manufactured, the price of which can bear the cost of recovering water from 'Bitterns'.

I. Cost Calculations of Heavy Water Production by Distillation of Water of different feed concentrations using H.London's formula (142).  

The production of D₂O by distillation of water at the and somewhat above the boiling point is considered. The equation used is

\[
\frac{W}{F} = \left(\frac{b}{\delta} \frac{\partial \pi}{\partial b}\right) \frac{RT \ln \frac{N_f + \Delta T_0 / T}{N_f}}{(L/R) \frac{\partial \pi}{\partial b} \eta_f}
\]

where,

- \( W \) = Expenditure in free energy
- \( F \) = Boles of feed to be separated
- \( b \) = A factor connecting the minimum boil up rate \( B_0 \) with the actual boil up rate \( B \).
- \( \delta \) = Enrichment factor (Separation factor - 1)
- \( \eta_f \) = Pressure drop across the fractionating column expressed as the ratio of the two pressures.
\( \Delta T_b \) = Temperature difference across the boiler condenser.

\( T \) = Process temperature.

\( \eta \) = Efficiency of the compressor.

\( L \) = Latent heat of vaporisation.

\( R \) = Gas constant.

The following values given by the author for different factors have been employed. For system \( \text{H}_2 \text{O}/\text{HD} \): \( \epsilon = 0.02 \); \( b = 1.5 \);
\( \ln \gamma = 0.60; \Delta T_b / T = 0.02; \) \( \text{K} = 12; \) \( \eta = 0.70 \) and \( T = 373^\circ \text{K} \).

Using these values in the above equation, one obtains

\[ \frac{\gamma}{\eta} = 2.1 \times 10^5 \text{ joules per mole feed.} \]

The mole of feed contains \( \text{HDO} = 2 \times 1.47 \times 10^{-4} \) moles.

To prepare \( 2 \times 1.47 \times 10^{-4} \) moles of the product, the energy required = \( 2.1 \times 10^5 \) joules.

For 50 moles of \( 1.7 \) g of the product, the energy required = \( 2.1 \times 10^5 \times 50 \) = \( 3.58 \times 10^{10} \) joules

\[ = 10^4 \text{ Kwh.} \]

Kwh required for one gram of product = \( 10^4/10^3 = 10 \text{ Kwh.} \)

Kwh required for 20 g or one mole of the product = 200 Kwh.

Considering the cost of 1 Kwh as \( 5 \) nP, the cost of one mole of \( \text{H}_2 \text{O} \) = \( 200 \times 5 = 1000 \) nP = \( 100 \) only.

Similar cost calculations with different concentrations of feed water have been given in Table 39.

II. Cost calculations of Heavy Water production by Dual-Temperature method by using F. Cerrai el al (145) Formula.

The formula employed for the calculation is:

\[ \frac{q}{p} = \frac{1}{\alpha \eta} - \frac{1}{\alpha - 1} \frac{1}{\alpha - 1} \left( 1 - \frac{1}{f} \right) - \frac{\ln f}{\ln \alpha} \quad \text{(184)} \]

\( N_p \) and \( q_a \) are the isotopic concentrations of the product and the feed respectively.

\( f \) = Total flow entering the plant

\( n \) = Unriched fraction withdrawn from the plant

\( \alpha \) = The ratio of the concentrations of the enriched fraction to the stripped one at any stage.

\( \eta \) = The prefixed enrichment.
Taking $n = 1.3, \beta = 300$ and $N_0$ as $0.00015$ mole fraction, the molar flow of the plant per mole of the heavy water produced is

$$\frac{F}{MW} = \frac{1}{0.00015} \cdot 2.32 \left( \frac{1.32}{0.997} - \frac{5.7}{0.277} \right)$$

$$= \sim 175,000 \text{ moles of water fed/mole of heavy water produced.}$$

Thus the moles of water fed per mole of heavy water produced can be calculated from which the reduction in cost of production of $D_2O$ using increasingly higher concentration of feed follows (as shown in Table 39).

I'. Cost calculation of heavy water production by any method by X. Cohen's equation, adopted by Benedict and Pigford

In an ideal cascade system, with stripping section making waste of optimum composition $x_0$, the cost of material of composition $x_p$ is

$$C_p = C_x \left[ 2 x_p -1 \right] \ln \frac{x_p(1-x_p)}{x_0(1-x_p)} + \frac{(x_p-x_0)(1-2x_0)}{x_p(1-x_p)} \right]$$

where $C_x$ = Unit cost of enriched material,

$C_p$ = Unit cost of separative work

$x_0$ = The composition of the waste

and $x_p$ = The composition of the final product

The above equation is used when the feed costs nothing and the waste can have the same composition as that of the feed.

Taking the $C_x$ value of one gram mole of heavy water as six rupees and using the value of $x_p$ and $x_0$ as $0.998$ and $0.00015$ mole fraction respectively, the unit cost of separative work is calculated.

$$6.00 = C_x \left( 2 x_0 -1 \right) \ln \frac{0.998 \times 0.999985}{0.9982 \times 0.9982} + \frac{0.99782 \times 0.99972}{0.00012 \times 0.99982}; C_x = 0.0009 \text{ rupees.}$$

With this calculated value of $C_p$, the $C_p$ values have been calculated for different feed concentrations, the results have been presented in Table 39.
Moles of Feed per Mole of D₂O

- Cost of Production of One g Mole RS.

- Mol Percent D₂O in Feed

- Equation (183)
- Equation (185)
- Equation (184)

Figure 33.
FIGURE 34.
PERCENTAGE REDUCTION IN COST VS. FEED CONCENTRATION.
Table showing the percentage reduction in the cost of production of heavy water by various methods.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Mole% D$_2$O</th>
<th>London's Formula</th>
<th>Gertel's Formula</th>
<th>Cohen's Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost/ mole</td>
<td>% Reduction</td>
<td>moles feed/ mole of D$_2$O</td>
<td>% Reduction</td>
</tr>
<tr>
<td>1</td>
<td>0.0150</td>
<td>9.72</td>
<td>195,000</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.0180</td>
<td>8.98</td>
<td>162,000</td>
<td>16.6</td>
</tr>
<tr>
<td>3</td>
<td>0.0200</td>
<td>7.30</td>
<td>146,250</td>
<td>25.2</td>
</tr>
<tr>
<td>4</td>
<td>0.0220</td>
<td>6.61</td>
<td>133,000</td>
<td>32.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0240</td>
<td>6.08</td>
<td>121,900</td>
<td>37.5</td>
</tr>
<tr>
<td>6</td>
<td>0.0250</td>
<td>5.94</td>
<td>117,500</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>0.0260</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The cost of production for one mole of D$_2$O by equation (183) and (185) and the water requirements for the production of one mole of D$_2$O by the equation (184) have been presented in Figure (33).

Calculations are made for the percentage reduction in the cost of production by using different concentrations of feed water over the cost of production using water of normal abundance. The calculated percentage reduction in cost against the molar percentage of feed have been presented in Figure (34).

The use of 'Bitters' as a feed material, the average concentration of Deuterium of which is 0.0240 mole percent, brings about a reduction in cost to the extent of 37.5% using any method for the production of heavy water.