Separation of alkali from silica-rich black liquor

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The black liquor produced from the pulping of rice straw with alkaline solution contains much silica which causes trouble during evaporation to obtain energy. The alkali material can be recovered by the use of a dialysis process. In this process, the factors affecting the efficiency of separation can be summarized as—volume of water used, time of the dialysis process, the concentration, and volume of black liquor, temperature, surface area, and types of membrane, vibration and stirring. The experiments showed that the period of time and the volume of water are related to each other, the best results were obtained with a small volume of water and a long time period. Half the concentration of the black liquor increased the efficiency of the dialysis. Also doubling the volume of black liquor to be dialyzed increased the dialysis efficiency. High efficiency can be obtained with less water and shorter time by using the appropriate membrane. The results confirmed that cellophane membrane dialyzed more grams of alkali than other dialysis membranes under the same conditions. Vibration of the liquor during the dialysis process increased the effect of the surface area. Increasing the temperature to about 50°C increased the dialysis efficiency and decreased both the volume of water and the time required.

Alkaline pulping of rice straw (the process used in Rakta Company, Alexandria, Egypt), produced black liquor with high content of silica, which causes severe problems during evaporation, combustion, and recovery of alkali, on using the conventional recovery method. To remove the silica scales formed on the evaporators wall, chemical solvents and mechanical process are to be used. For this reason, most alkaline straw pulp mills are unable to recover alkali from the black liquor, and they had to discharge it in the sea water causing heavy environmental pollution, especially for the marine biota, i.e., fishes. According to Ibrahim, for the black liquor of rice straw pulping, the smooth recovery of chemicals and heat is rendered impossible by the high silica content. Evaporator scales of sodium silicate and other insoluble silicates (Ca, Al) require periodic stoppage and physical or chemical cleaning. With the conventional method, extensive deposits are formed in the upper section of recovery boiler owing to the high ash content of the black liquor being burned and the volatile nature of the ash, besides severe corrosion of super heater tubes in a recovery boiler. Corrosion was found in all the zones tested, and the rate of corrosion sharply increased in the lower part of the shielding tubes, besides this boiler explosion caused by water leaking from corroded tubes and reaching the smelt. Thus, the aim of this work is the recovery of pure alkali from alkaline pulping black liquor using membrane technology, called dialysis process, the remains of which are organic substances such as lignin and carbohydrates that can be used as a source of energy without any troubles.

Experimental Procedure

Cooking process
Rice straw was cooked for 2 h at 160°C with 10% caustic soda at a liquor ratio of 1:4.

Preparation of black liquor
The spent cooking liquor from the digestion plus the filtrate from the washing operation are collected together, filtered and analyzed as quickly as possible, since the analyzed sample must be fresh.

Analysis of black liquor
Solid content—Total dissolved solids in the liquor was determined by two methods—
(a) Evaporation method, in which a known volume
of black liquor was taken into a weighing dish and weighed as quickly as possible. After 24 h in a 105°C oven the dish is cooled in a desiccator, and weighed. The solid content is calculated according to the equation, 

\[
\% \text{ Solid content} = \frac{W_2}{W_1} \times 100
\]

where, \( W_1 \) is the original weight and \( W_2 \) is the dry weight.

(b) **Precipitation method**, in which black liquor was treated with 10% hydrochloric acid to precipitate solid, using water-bath at 100°C for an hour, then filtered using ashless filter paper. After 24 h in a 105°C oven, cooled in a desiccator and weighed.

**Ash content**—The dried sample is slowly ignited in a muffle furnace, left at 400°C for 30 min and then at 850°C for 45 min and then estimated gravimetrically.

\[
\% \text{ Ash content} = \frac{W_2}{W_1} \times 100
\]

where, \( W_1 \) is the weight of dry sample and \( W_2 \) is the weight after ashing.

**pH**—Concentration of OH group can be measured using pH-electrode, after adjusting it with different standard solution at variable pH.

**Density** (g/cm³)—A known volume of black liquor was taken into a clean dry weighing dish, weighed as quickly as possible and the density was calculated by dividing the weight by volume.

**Viscosity**—The viscosity of the black liquor is measured using Ostwald's viscometer, by observing the time required for a definite volume of the black liquor to flow through a standardized capillary tube under a known difference of pressure. The same experiment was carried out using water. The relative viscosity was calculated from the equation:

\[
\eta_{\text{relative}} = \frac{\eta_0 \times t_0 d_0}{t_1 d_1}
\]

where, \( \eta_0 \) is the viscosity of water, \( t_0, t_1 \) is the flow time of water and black liquor respectively, \( d_0, d_1 \) is the density of water and black liquor respectively, and \( \eta_{\text{relative}} \) is the relative viscosity of black liquor.

When black liquor is concentrated to 50%, Rheomat 15T instrument was used and the viscosity was calculated using the formula,

\[
\eta = \frac{\text{Shear stress per scale unit (r %).%reading}}{\text{Shear rate}}
\]

**Total alkalinity**—Total alkalinity of black liquor before and after dialysis were determined using: pH-meter titration, acidimetric techniques and M.O. (methyl orange) end point. The total alkalinity is expressed at Na₂O.

(a) **pH-meter titration**—A known volume of black liquor was titrated against 0.5 N HCl to pH 3.5 using digital pH-instrument. The sample of the black liquor taken was fresh, because the pH decreases with prolonged storage. If the pH falls below a critical value, sorption or precipitation of lignin fragments, and hemicellulose can occur.

(b) **Acidimetric techniques**—Sample of dilute black liquor was acidified with a definite volume of 0.5 N HCl (boiling to expel CO₂). The excess acid was titrated with 0.1 N NaOH using methyl orange indicator (M.O.). 1/5 volume of 0.1 N NaOH was subtracted from the volume of 0.5 N HCl. The amount of 0.5 N HCl required to neutralize total alkalinity is obtained according to,

\[
1 \text{ mL } 0.5 \text{ N HCl} = 0.01550 \text{ g Na}_2\text{O}
\]

(c) **End point**—(Used only for the dialyze water) A known volume of the dialyzate was titrated against 0.05 N HCl using M.O. indicator. The normality of Na₂O was calculated using equation, \( N_1V_1 = N_2V_2 \). The grams of total alkalinity (G) (expressed as Na₂O) was calculated as,

\[
\frac{N(Na_2O)X_{eq.wt}XV(\text{dialyze})}{1000} = G(Na_2O)
\]

**Concentration of black liquor**

Black liquors were concentrated to 50 and 30% using both water bath at 100°C for 4 h with gentle stirring and Rota-vapour instrument at 110°C.

**Dialysis processes using multiple dialyzer instrument**

Membrane of Pope dialysis tube were filled with black liquor (Fresh sample) and dialyzed in water (dialyze) for a period of time in Multiple Dialyzer Instrument.

Different types of membrane (Protein dialysis bags and Cellophane bags), using different volumes and concentrations of black liquor, and also different period of times and volume of water were used.
### Table 1—Properties of black liquor before dialysis

<table>
<thead>
<tr>
<th>Experimental number</th>
<th>Experimental type</th>
<th>Solid content of black liquor kg/100 mL</th>
<th>Ash content g/100 mL</th>
<th>pH</th>
<th>Density g/cm³</th>
<th>Total alkalinity in the black liquor, g</th>
<th>Volume of black liquor used, mL</th>
<th>Volume of water used, mL</th>
<th>Dialysis time h</th>
<th>Dialysis efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Laboratory black liquor precipitation</td>
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<td>25.12</td>
<td>0.58</td>
<td>6.58</td>
<td>10.4</td>
<td>1.094</td>
<td>5.79</td>
<td>200</td>
<td>9</td>
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<tr>
<td>7</td>
<td>concentrated to 50% at 25°C precipitation</td>
<td>5.05</td>
<td>21.85</td>
<td>0.78</td>
<td>5.04</td>
<td>10.3</td>
<td>1.078</td>
<td>7.58</td>
<td>400</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>50% at 25°C precipitation</td>
<td>5.05</td>
<td>21.85</td>
<td>0.78</td>
<td>5.04</td>
<td>10.3</td>
<td>1.078</td>
<td>7.58</td>
<td>400</td>
<td>2</td>
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</table>

### Table 2—Effect of the volume of water and the time on the dialysis efficiency

<table>
<thead>
<tr>
<th>Expt. no.</th>
<th>Expt. type</th>
<th>Analysis of black liquor before dialysis</th>
<th>Analysis of black liquor after dialysis</th>
<th>Expt. type</th>
<th>Analysis of the dialyze</th>
<th>Number of NaOH grams present in the dialyze per liter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid content of black liquor g/100 mL</td>
<td>Ash content of black liquor g/100 mL</td>
<td>pH</td>
<td>Density g/cm³</td>
<td>Total alkali in the black liquor used g</td>
<td>Volume of black liquor used mL</td>
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<td>7</td>
<td>a</td>
<td>5.05</td>
<td>21.85</td>
<td>0.784</td>
<td>5.04</td>
<td>10.3</td>
</tr>
<tr>
<td>23</td>
<td>b</td>
<td>5.38</td>
<td>23.04</td>
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<td>24</td>
<td>c</td>
<td>4.43</td>
<td>17.30</td>
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<td>9</td>
<td>d</td>
<td>5.05</td>
<td>21.85</td>
<td>0.784</td>
<td>5.04</td>
<td>10.3</td>
</tr>
</tbody>
</table>

(a) Laboratory black liquor concentrated to 50% with 9 L of water at 25°C for 10 h; (b) Laboratory black liquor concentrated to 50% with 4.5 L of water at 25°C for 5 h; (c) Laboratory black liquor concentrated to 50% with 4 L of water at 25°C for 10 h; (d) Laboratory black liquor concentrated to 50% with 2 L of water at 25°C for 5 h.
Dialysis process using membrane stretched on a funnel mouth

Cellophane sheet stretched on a funnel mouth (diameter 13.6 cm), filled with known volume of black liquor was dialyzed in a known volume of water (dialyzate) for a definite period of time. Repeated experiments with different volumes and concentrations of black liquor and different period of times and volumes of water were performed. Also this experiment was carried out either in the stationary or vibrational state, by using water pump or magnetic stirrer. Moreover, the cellophane sheets were covered with wire or CCl₄ was used to protect the membrane being tested.

Results and Discussion

Dialysis process uses a transport membrane in which solute molecules are exchanged between two liquids. It depends on the difference in chemical potentials between the liquids. It is used both for removing excess low molecular-weight solute and simultaneously introducing a new buffer solution (it may be just water) to the sample. Dialysis requires that the membrane separating the liquid permit diffusional exchange between at least some of the molecular species while effectively preventing any convective exchange between the solutions.

In the present work, dialysis process was performed to isolate the alkali of the soda which is produced from the alkaline cooking of rice straw to obtain paper pulp. The factors affecting the efficiency of the dialysis process are,

(i) Volume of water used and time of the dialysis process, (ii) concentration and volume of black liquor used, and temperature, (iii) type of membrane, (iv) vibration and stirring, and (v) surface area of the membrane.

Properties of black liquor before dialysis

The black liquor used for dialysis was analyzed for solid and ash content, pH value, total alkalinity (expressed as Na₂O), density, and viscosity. Black liquor sample must be freshly prepared, because the pH of the black liquor falls owing to transformation of some of sodium hydroxide to sodium carbonate through the carbon dioxide present in the air. The results are given in Table 1.

Factors affecting the efficiency of dialysis process

Effect of volume of water used and dialysis time on the dialysis efficiency—Dialysis time and volume of water used to receive the sodium ions (dialyzate) are related to each other, since the dialysis process ends when there is no ionic mobility across the membrane, at this stage the water must be changed. Table 2 shows that decreasing both the quantity of water used from 9 to 4.5 L, and time period of the dialysis process from 10 to 5 h, decreased the dialysis efficiency from 94.98 to 70.36% (Expt No. 7, 23, Table 2), while on decreasing only the volume of water from 9 to 4 L and using the same period of time, decreased the dialysis efficiency from 94.98 to 89.49% (Expt. No.7 and 24 respectively). Using approximately the same quantity of water and decreasing the period of time from 10 to 5 h, decreased the dialysis efficiency from 89.49 to 70.36% (Expt. No.23 and 24). Carrying out the chemical analysis on the dialyzate to determine the grams of alkali per litre it was found that decreasing the volume of water from 9 to 4 L over the same period of time, increased the grams of alkali per litre from 1.45 to 3.07 g/L (Expt. No.7 and 24).

Decreasing both the volume of water from 9 to 2 L and time from 10 to 5 h, increased the number of grams of alkali present per litre dialyzate from 1.45 to 4.40 g/L (Expt. No.7 and 9 respectively, Table 2). But on using approximately the same volume of water, and decreasing the time of dialysis from 10 to 5 h, grams of alkali present per one litre of the dialyzate decreased from 3.07 to 2.15 g/L (Expt. No.24 and 23 respectively). So the best efficiency of the dialysis can be obtained using a longer period of time and changing the water many times, at least twice.

Effect of concentration and volume of black liquor and temperature on the dialysis efficiency—Black liquor was concentrated to 50% of its original volume. Concentration was affected through evaporation at 110°C using Rota-vapour or using water-bath at 100°C.

200 mL laboratory prepared black liquor concentrated to 50% using Rota-vapour or water bath were subjected for dialysis using 9 L of water, for 12 h (4.5 L for 5 h, then replaced by another 4.5 L for 7 h) (Expt. No. 2 and 5). Blank experiments were carried out on unconcentrated black liquor (original) for comparison (Expt. No. 1 and 4, Table 3).

Effect of vibration and stirring on the dialysis efficiency—Studies on the effect of vibration and stirring on the recovery efficiency have been done by the use of a multiple dialyzer instrument (both in
the stationary and electrical vibration state), and stirring (in which either magnetic stirrer or water pump to circulate the water were used). From the results gathered in Table 4, comparison between dialysis efficiency of Expt. No.13 and 14 (93.2 and 94.62% respectively), and that of Expt. No. 16 and 17 (91.58 and 92.06% respectively) showed a significant increase in the dialysis efficiency by using electrical vibration state of the multiple dialyzer instrument, while dialysis efficiency obtained in Expt. No. 18 (65.57%), in which water was circulated by pump, was increased greatly with that obtained in Expt. No. 17 (54.24% for the stationary state). Also, time of the dialysis process was decreased from 24 h (Expt. No.17) to 5 h (Expt. No.18). This can also be noticed if Expt. No. 22 and Expt. No17 (where the dialysis efficiencies recorded 24.76 and 54.24% respectively) are compared with Expt. No.18 (65.50%). The use of water circulation is preferable than the use of magnetic stirrer and the dialysis stationary.

Effect of type of membrane on the dialysis efficiency—200 mL of the laboratory original black liquor were dialyzed in 4.5 L of water for 1 h and the three different types of membrane bags having the same area, namely, bags of the multiple dialyzer instrument (Pope dialysis tubes), protein dialysis bags, and cellophane dialysis bags, were used to investigate the effect of type of membrane on the dialysis efficiency.

Comparison between the three different types of membranes used, indicates that the highest efficiency was achieved after one hour of dialysis using the cellophane membrane. Extending the time of dialysis to 5 h using the membrane of multiple dialyzer instrument and protein dialysis bags, increased the dialysis efficiency and nearly equalized that on using cellophane membrane (Table 5). In other words, the efficiency after one hour of dialysis using cellophane membrane was achieved after 5 h using multiple dialyzer instrument and protein dialysis membranes.

At 5 h dialysis, equilibrium was attained, i.e., no more transfer of Na+ ions takes place through the membrane (Expt.No.25 and 26, Table 5). Therefore, the dialyzate was replaced by another 4.5 L fresh water, and the dialysis process was completed for 12 h, where the dialysis efficiencies increased to 93.22 and 94.62% for Expt. No.25 and 26 respectively (Table 5). Thus, the membrane has a great effect on the process of dialysis, as it can highly decrease the time of dialysis. Also, high efficiency may be obtained with less amount of water on using the appropriate bag membrane.

Effect of surface area of membrane on the dialysis efficiency—Studies on the effect of surface area of the membrane on the dialysis efficiency showed that, the amount of separated alkali (g/cm²), where total grams of alkali separated was divided by the area of the membrane, used in the separation, using cellophane membrane, both in the stationary and vibration states, were higher than those obtained using multiple dialyzer instrument tubes and protein dialysis bags (Table 6), which means that, 1 cm² of cellophane membrane dialyzed more grams of alkali than 1 cm² of the other dialysis tube for the dialysis process of black liquor, i.e., cellophane membrane is more efficient than other membranes.

Table 6 also shows that, vibration state has a significant effect on the separation of alkali. Since in Expt. No.13 and 15 & 18 and 17, the grams of separated alkali/cm², in the vibrational state, was higher than that of the stationary state. This means that, the vibration of the liquid during dialysis increased the effect of the surface area. Summing up, the surface area influences the efficiency of the dialysis process.

Properties of black liquor after dialysis
Table 7 shows a distinct decrease in the pH value, solid, ash and total alkali contents for the black liquor subjected to a dialyzing process for longer periods (10 and 12 h) and using large volumes of water—9 L for dialysis (changed 2 times, each one 4.5 L), compared with the corresponding volume before dialysis, Table 1. This again indicates the diffusion of most of the Na⁺ ions present in the liquor, through the membrane to the dialyzate. However, the decrease in the values of pH, solid, ash and total alkali contents was lesser for the black liquor subjected to dialysis for short period (5 h) and small volume of water of dialysis (2 L at a time, Table 7) in comparison to the corresponding values before dialysis (Table 1), indicating less diffusion of the Na⁺ ions present in black liquor to the dialyzate. It is noticeable that, in general, there is an increase in the volume of black liquor subjected to the process of dialysis (Table 7) in comparison to the corresponding volume before dialysis (Table 1). This relates to the presence of an empty space in the dialysis bag, in which water diffuses from the
Table 3—Effect of concentration, volume of black liquor and temperature on the dialysis efficiency

<table>
<thead>
<tr>
<th>Expt no</th>
<th>Expt type</th>
<th>Solid content of black liquor g/100 mL</th>
<th>Ash content of black liquor g/100 mL</th>
<th>pH</th>
<th>Density g/cm³</th>
<th>Total alkali in the black liquor used, g</th>
<th>Volume of the black liquor used L</th>
<th>Dialysis efficiency %</th>
<th>Solid content of black liquor g/100 mL</th>
<th>Ash content of black liquor g/100 mL</th>
<th>pH</th>
<th>Density g/cm³</th>
<th>Total alkali in the black liquor, g</th>
<th>Volume of water used L</th>
<th>Dialysis efficiency %</th>
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<td>Rota-</td>
<td>a</td>
<td>1.099 9.28 0.032 2.39</td>
<td>10.0 1.033 5.29</td>
<td>200 9.0 12 4.82</td>
<td>94.19</td>
<td>0.251 1.57 0.011 0.132 7.1</td>
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<td>3.940 36.25 0.215 4.41</td>
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<td>bath</td>
<td>e</td>
<td>4.520 25.12 0.855 6.58</td>
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<td>400 9.0 10 4.18</td>
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<td>0.313 3.38 0.001 0.556 9.7</td>
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<tr>
<td>at</td>
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<td>5.050 21.85 0.784 5.04</td>
<td>10.3 1.078 7.58</td>
<td>400 9.0 12 7.20</td>
<td>94.98</td>
<td>1.960 5.76 0.180 0.728 9.8</td>
<td>1.012 0.686 550</td>
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<td>94.98</td>
<td>1.960 5.76 0.180 0.728 9.8</td>
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Table 4—Effect of vibration and stirring on the dialysis efficiency

<table>
<thead>
<tr>
<th>Expt No</th>
<th>Expt type</th>
<th>Solid content of black liquor g/100 mL</th>
<th>Ash content of black liquor g/100 mL</th>
<th>pH</th>
<th>Density g/cm³</th>
<th>Total alkali in the black liquor used, g</th>
<th>Volume of the black liquor used L</th>
<th>Dialysis efficiency %</th>
<th>Solid content of black liquor g/100 mL</th>
<th>Ash content of black liquor g/100 mL</th>
<th>pH</th>
<th>Density g/cm³</th>
<th>Total alkali in the black liquor, g</th>
<th>Volume of water used L</th>
<th>Dialysis efficiency %</th>
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<tr>
<td>Vibration</td>
<td>a</td>
<td>3.229 13.27 0.132 2.99</td>
<td>10.0 1.043 5.94</td>
<td>200 0.541 3.26</td>
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<tr>
<td>b</td>
<td>2.644 12.46 0.052 2.72</td>
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<td>200 0.251 1.56</td>
<td>0.001 0.132</td>
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<td>200 0.714 3.06</td>
<td>8.400 0.092</td>
<td>8.1 1.004 0.251</td>
<td>340 9 12 5.05 91.58</td>
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<td>d</td>
<td>2.644 12.46 0.052 2.78</td>
<td>10.0 0.939 5.09</td>
<td>200 0.510 6.65</td>
<td>4.200 0.077</td>
<td>8.6 0.996 0.273</td>
<td>280 9 12 4.69 92.06</td>
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<tr>
<td>Using</td>
<td>a</td>
<td>2.865 12.49 0.135 4.11</td>
<td>9.9 1.045 12.70</td>
<td>500 1.830 6.65</td>
<td>0.150 1.489</td>
<td>7.7 1.015 4.960</td>
<td>598 2 24 6.90 54.24</td>
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<tr>
<td>water</td>
<td>b</td>
<td>1.099 12.28 0.083 2.39</td>
<td>10.0 1.035 12.70</td>
<td>500 2 5 8.40 65.50</td>
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<tr>
<td>pump</td>
<td>c</td>
<td>1.099 12.28 0.083 2.39</td>
<td>10.0 1.035 12.70</td>
<td>500 2 5 8.40 65.50</td>
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<tr>
<td>Using</td>
<td>d</td>
<td>1.014 9.98 0.073 2.34</td>
<td>9.8 1.014 8.76</td>
<td>500 2 5 8.40 65.50</td>
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</tr>
</tbody>
</table>

a = Laboratory black liquor at 25°C using Pope dialysis bags; b = Laboratory black liquor at 25°C using protein dialysis bags; c = Laboratory black liquor at 25°C using cellulose sheet stretched on the funnel mouth; d = Laboratory black liquor at 25°C using cellulose sheet, and water pump; e = Laboratory black liquor at 25°C using cellulose sheet covered with wire; f = Laboratory black liquor at 25°C using cellulose sheet, and CCL at the end of the experiment; g = Laboratory black liquor at 25°C using cellulose sheet; h = Laboratory black liquor at 25°C using cellulose sheet, and magnetic stirrer
dialyzate through the membrane to fill this space. This was confirmed by leaving no empty space in the bag and in such case, the volume of black liquor after dialysis remained unchanged in comparison to the corresponding volume before dialysis (Expt. No. 9, Tables 7 and 1).

**Conclusion**

1. On decreasing both the volume of water used and the period of time to half, (Expt. No. 7, 23 and 24 respectively), the weight of alkali per litre of the dialyzate increases.

2. On decreasing only the volume of water used over the same period of time, the weight of alkali/L show high increase in the dialyzate (from 1.45 to 3.07 g/L and from 3.07 to 4.40 g/L Expt. No. 7, 24 and 9 respectively).

3. On using approximately the same volume of water but decreasing the period of time to half (Expt. No. 23 and 24 respectively), the grams of alkali/L of the dialyzate decreases from 3.07 to 2.15 g/L (Table 2).

4. On concentrating the black liquor to 50%, the dialysis efficiency increases.

5. On concentrating the black liquor to 50%, and on volume to be dialyzed being doubled, dialysis efficiency is increased.

6. Higher dialysis efficiency was achieved on carrying out the process of dialysis at high temperature.

7. Vibration of the liquid during dialysis increased the effect of the surface area.

8. High efficiency may be obtained with less amount of water on using the appropriate bag membrane.

9. There is an increase in the volume of the liquor and distinct decrease in the pH value, solid, ash and total alkali contents for the black liquor subjected to the process of dialysis.

10. Comparison between the two processes, evaporation and dialysis, for the recovery of alkali from black liquor, indicated that even the black liquor which contains little percent of silica, resulting from pulping of the bagasse, cannot be recovered by the conventional evaporation method, since on increasing the concentration of the black liquor to more than 50% increases the viscosity of the solution causing problems during the incineration of the black liquor. So, the black liquor,

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>Types of membrane bags</th>
<th>Volume of water used in the dialysis process, L</th>
<th>Dialysis time, h</th>
<th>Total alkali in the dialyzate, g</th>
<th>Lignin content precipitated, g</th>
<th>Ash content, g</th>
<th>Dialysis efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Bags of the multiple dialyzer instrument (Pope dialysis tubes)</td>
<td>4.5</td>
<td>1**</td>
<td>2.669</td>
<td>0.7310</td>
<td>4.837×10^4</td>
<td>44.89</td>
</tr>
<tr>
<td>26</td>
<td>Protein dialysis bags</td>
<td>4.5</td>
<td>12***</td>
<td>5.544</td>
<td>0.3167</td>
<td>5.460×10^4</td>
<td>93.22</td>
</tr>
<tr>
<td>27</td>
<td>Cellophane dialysis bags</td>
<td>4.5</td>
<td>1</td>
<td>3.778</td>
<td>0.3515</td>
<td>1.927×10^3</td>
<td>94.62</td>
</tr>
</tbody>
</table>

* = Dialysis after using 4.5 L H₂O; ** = Extention of the time of dialysis to 5 h using the same amount of H₂O (4.5 L); *** = Extention of the time of dialysis till 12 h after replacing the water of dialysis with another 4.5 L (total volume of H₂O used was 9 L)

<table>
<thead>
<tr>
<th>Experimental conditions</th>
<th>Experimental number</th>
<th>Experimental type</th>
<th>Dialysis efficiency</th>
<th>Total alkali separated in the dialyzate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stationary state</td>
<td>15</td>
<td>using Pope dialysis tubes</td>
<td>91.58</td>
<td>0.01350</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>using protein dialysis tubes</td>
<td>92.06</td>
<td>0.01366</td>
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<tr>
<td></td>
<td>17</td>
<td>using cellophane sheet stretched on a funnel mouth</td>
<td>54.24</td>
<td>0.04755</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>using Pope dialysis tubes</td>
<td>93.22</td>
<td>0.01374</td>
</tr>
<tr>
<td>Vibrational state</td>
<td>14</td>
<td>using protein dialysis tubes</td>
<td>94.62</td>
<td>0.01390</td>
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<tr>
<td></td>
<td>18</td>
<td>using cellophane sheet stretched on a funnel mouth (with water circulation)</td>
<td>65.57</td>
<td>0.05750</td>
</tr>
</tbody>
</table>
which contains little or higher per cent of silica, can be recovered by the dialysis process.

11 Many advantages can be noticed with the dialysis process, since it is considered as a simple process with less consuming power than the present processes such as combustion\textsuperscript{10-12}, carbonation\textsuperscript{13-15}, iron-oxide\textsuperscript{16-23}, electrolysis\textsuperscript{24}, electrodialysis-ion exchange membrane\textsuperscript{25,26}, and physico-chemical purification processes\textsuperscript{27}. Also, cellophane membrane used in this process can be obtained industrially from viscose solution, and it can be used for several times. Moreover, the organic compounds separated from the dialysis process, such as lignin, can be safely used in the production of heat without any effects on the boiler walls. On the other hand, after the recovery of the alkali (soda) from the black liquor, and the utilization of the organic compounds (lignin), there will be no environmental water pollution caused by the black liquor.

References
8 ASTM Bull, 1957.