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# Colour and Chloride Removal from Pulp Mill Effluent Using Ion-Exchange Resins

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# Colour and Chloride Removal from Pulp Mill Effluent Using Ion-Exchange Resins

SFM Network Project: Reactor Design for Enzyme Catalyzed Colour Removal from Pulp Mill Effluent

by

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# ABSTRACT

A preliminary set of colour removal tests using soluble Horseradish peroxidase, Arthromyces ramosus peroxidase, and tyrosinase (polyphenol oxidase), indicated that these enzymes were not able to remove colour from pulp mill effluent. However, a previous study indicated that anion exchange resins were very effective at colour removal. Therefore, the focus of this study was shifted to a preliminary investigation of colour and chloride ion removal by anion exchange resins.

All tests were conducted at bench scale and in batch mode. Six strong base anion exchangers were evaluated to compare their colour removal capacities. The effluent colour was reduced with all resins tested. An acrylic gel resin, Amberlite® IRA-458, and a macroreticular resin, Amberlite® IRA-900, showed superior capacities to the other resins tested including Amberlite® IRA-400, IRA-402, IRA-410, IRA-458 and IRN-78. Although the majority of colour and chloride was successfully removed from effluent with IRN-78, which is a hydroxide-form resin, chloride concentration increased after the treatment with chloride-form resins. Chloride could be removed with IRN-78 used either simultaneously with or subsequent to the colour removal; however, increase in chloride concentration after colour removal with chloride-form resins was so significant that it may cause a increase in resin demand for a complete removal of chloride. Further research is required to find resins with better performance in colour and chloride removal from pulp mill effluent. Further investigation of colour and chloride removal with same resins in a flow through column as well as regeneration of spent resins is also required. This anion exchange process has potential application in progressive plant closure in combination with other technologies such as cation exchange.

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# INTRODUCTION

Although the environmental impact of the pulp and paper industry has been decreased by the development of new and improved production processes as well as waste treatment systems (Odendahl 1994), some concerns such as the residual colour of pulp mill effluent still remain. Problems associated with the coloured effluent are sometimes considered not to be critical (Jurasek and Paice 1986); however, the colour may cause a potential damage to aquatic life through the inhibition of light penetration into water and is not favourable for aesthetical reasons. In addition, unlike the removal of oxygen demands, such as BOD and COD, suspended solids, and toxicity, which can be successfully removed by primary treatment and following biological treatment, colour are extremely difficult and expensive to remove. There are several practicable technologies available including membrane technology, fungal decolourisation, and ozonation; however, they are not always ready to meet increasingly stringent effluent colour standards under different circumstances.

It is generally believed that the major sources of colour from pulp mill effluent are lignin and its derivatives (Paice and Jurasek 1984). Within the plant cell, lignin chemically binds with polysaccharide components to reinforce its mechanical strength and prevent its decay by microorganisms (Higuchi 1980). During the extraction stages of pulping, lignin is digested and separated from fibre and causes coloured effluents. The colour of lignin is generally light yellow with an absorption peak at aromatic 280 nm and a shoulder around 340 nm which is gradually declining to the longer wavelength (Falkehag et al. 1966). According to Falkehag and coworkers, the lignin chromophores are likely to be caused by stilbene and quinonoid structures (quinonemethides), and their polymerised and/or condensed compounds, which are formed during kraft cook Whereas low molecular weight lignin molecules are readily biodegradable through oxidative ring-cleavage reactions (Cain 1980), high molecular weight lignin, which is three-dimensionally polymerised with several different carbon-carbon and ether linkage, is highly resistant to hydrolysis and microbial degradation (Higuchi 1990). Recently, Santos and Duarte (1998) reported that the aquatic humic substances found in a Portuguese river, which receives a discharge from a pulp and paper plant, were likely to be originated from the lignin-derived macromolecules from the effluent.

Previously, decolourisation of kraft pulp mill effluents in northern Alberta using immobilised horseradish peroxidase had been attempted in our laboratory (Grant 2000). Unlike the former results reported in the literatures (Ferrer et al. 1991; Peralta-Zamora et al. 1998a), the immobilised horseradish peroxidase had failed to remove the colour; however, the ion-exchange resin IRA-400, which was used as a support material for the enzyme, had shown a promising ability to remove the colour (Grant 2000). A preliminary set of colour removal tests that were performed during the present study using soluble Horseradish peroxidase, Arthromyces ramosus peroxidase, and tyrosinase (polyphenol oxidase), indicated that these enzymes were not able to remove colour from pulp mill effluent.

In the mid 1970s, an ion exchange technology had been evaluated for colour reduction in dissolving sulfite, kraft and thermomechanical pulping plant effluent (Fitch 1982). It is reported that a full-scale batch ion-exchange system was successfully reducing colour discharges by approximately 90% and capable to remove other pollutant including chlorinated phenols, chlorinated guaiacols, and COD. Some literatures also stated that a strong base anion exchanger IRA-400 had a substantial ability to remove colour from kraft E1 effluent (Peralta-Zamora et al. 1998a; Peralta-Zamora et al. 1998b). However, these reports are base on the results of the colour removal from chlorine gas (CG) bleaching effluents. No study has been reported so far about the application of ion-exchange technology to the colour removal from the effluents from elementary chlorine free (ECF) bleaching processes, which is now commonly used in northern Alberta pulp mills. It is dangerous to expect that the ion-exchange technology is also effective to remove colour from the ECF bleaching effluents because of the difference in the chemistry of delignification between two bleaching processes that may cause dissimilar chromophores. Therefore, further research is required to evaluate the applicability of this technology to the kraft pulp mills in Alberta.

## Colour Removal Using Anion Exchange Resins

Many types of strong base anion exchangers are commercially available from several manufacturers. They are classified by several factors such as the functional group for ion exchange, and the structure of resin including structural materials, porosity, moisture content, and density (James M. Montgomery 1985). There are two functional groups for strong base anion exchangers, one is benzyl-trimethyl-ammonium group (type I), and the other is benzyl-dimethylethanolamine group (type II). Whereas the type I resins are more chemically stable, the type II resins have slightly higher regeneration efficiency. Several structural materials of resin are available including cellulose, styrene-divinyl benzene copolymer, and polyacrylic gels. The cross-linking ratio of polymers greatly affects the porosity and moisture content of resins. The selectivity of ionic species increases with increasing valence of the exchanging ion and with decreasing hydrated radius at low aqueous ion concentrations. However, as the ionic strength of a solution increases, the preference for polyvalent ions over monovalent ions diminishes.

In water treatment, it is known that naturally occurring humic substances are amendable to remove from groundwater and surface water using macroporous anion exchangers in the chloride form (Kolle 1979; Brattebo et al. 1987). Since some of the humic substances in natural water system are possibly derived from natural degradation of plant lignin as well as from pulp industry (Santos and Duarte 1998), the macroporous resins may have greater affinity to the colour causing compounds existing in kraft pulp mill effluent, however, only the use of a gel type IRA-400 resin has been reported so far. Therefore, further research with various types of resins is required to find a suitable resin for the removal of colour from the kraft pulp mill effluent.

## Chloride Removal

Although colour removal is the primary goal, strong base anion exchangers are also possible to remove non-process anions, such as chloride, existing in the waste stream. In combination with cation removal using either chemical precipitation, membrane processes, or ion exchange, the anion removal is possibly useful for effluent recycle and for potential applications in plant closure. Among the non-process anions, chloride is one of the most ubiquitous and difficult to remove. In addition, it is significantly corrosive to steel and aluminium at levels of 50 mg/L or even less (James M. Montgomery 1985). Therefore, the chloride concentration in the treated effluent with ion exchange resin should also be monitored. Since required resin characteristics for colour and chloride removal may be different, sequential removal of those target pollutants can be considered.

## Research Requirements

While the ion-exchange process was identified and investigated as a possible means of colour removal from pulp mill effluent long time ago (Fitch 1982), little research has been conducted in this area today. In order to update the applicability of this technology to colour removal from ECF bleach plant effluents, a study to identify suitable resins is required. At the same time, the possibility to remove chloride during the colour removal must be studied. Although the construction of continuous flow ion-exchange column is the final form of treatment, all tests conducted here are in bench scale and batch mode because this is a preliminary investigation.

## Study Goals

The goals of this study are follows:

- To investigate the use of ion exchange process to remove colour from pulp mill effluent;
- To monitor the concentration of chloride as a measure of non-process anions during the colour removal; and
- To explore the possibility to remove chloride from the effluent.

# MATERIALS AND METHODS

Final effluent was provided from the Weyerhaeuser kraft pulp mill, Grande Prairie, AB, and stored at 4°C. Effluent has characteristics of clear yellow colour with 1041 platinum-cobalt colour unit (PCU), pH 7.9, and 264 ppm of chloride. Six strong base anion exchangers, including Amberlite® IRA-400, IRA-402, IRA-410, IRA-458, IRA-900 and IRN-78, were purchased from Sigma-Aldrich Canada Ltd., Oakville, ON. Characteristics of these resins are presented in Table 1. Other chemicals used in this study were purchased either from Fisher Scientific Canada, Edmonton, AB and Whitby, ON or from Sigma-Aldrich Canada Ltd.

Table 1. Characteristics of the resins tested

| Name | Type | Matrix | Ionic Form | Total Capacity (meq/g) |
|---|---|---|---|---|
| Amberlite® IRA-400 | Type I | Styrene-DVB Gel | $Cl^-$ | 3.8 |
| Amberlite® IRA-402 | Type I | Styrene-DVB Gel | $Cl^-$ | 4.1 |
| Amberlite® IRA-410 | Type II | Styrene-DVB Gel | $Cl^-$ | 3.4 |
| Amberlite® IRA-458 | Type I | Acrylic gel | $Cl^-$ | 4.4 |
| Amberlite® IRA-900 | Type I | Styrene-DVB Macroreticular | $Cl^-$ | 4.2 |
| Amberlite® IRN-78 | Type I | Styrene-DVB Gel | $OH^-$ | 4.0 |

The detailed procedure for colour test used in this study is described in elsewhere (Grant 2000). A Hewlett Packard HP 8453 UV-Vis spectrophotometer and an Orion combination pH electrode model 91-05 with a Fisher Accumet® pH meter model 805 were used for colour test. An Orion combination electrode chloride model 96-17B with Fisher Accumet® pH meter 50 was used for the measurement of chloride concentration. A direct calibration method described in the instruction manual reference of chloride electrode was used as an analytical procedure for chloride measurement.

Ultra pure water produced by Elgastat Maxima HPLC water purification system (Elga Ltd., High Wycombe, Bucks, England) was used for sample dilution at the chloride concentrations of lower than the detectable limit (< 1.8 ppm) of the chloride electrode used.

Ion-exchange treatment was conducted in a 120 mL glass vial with lids. An aluminum foil cover was provided to prevent any photochemical degradation of constituents. Final effluent was treated either diluted or undiluted without pre-filtration. Sample volume was 100 mL otherwise indicated. Samples were gently stirred with magnetic stirrer for one day at 21°C. After one day of contact with resin, all samples were filtered through borosilicate glass fibre filters (pore size 2.5 µm) followed by cellulose membrane filters (pore size 0.8 µm) prior to the colour and chloride measurement. All treatments were duplicated, and control vials were also prepared.

# RESULTS

## Screening of the Resins for Decolourisation of Pulp Mill Effluent

Six types of strong base ion-exchange resins were selected for this study. Batch colour removal experiments were conducted in order to compare the colour removal capacity of these resins. Increasing amounts of resin ranging from 2 g/L to 400 g/L were added to pulp mill final effluent diluted with pure water (no dilution, 50% and 25%). After one day of gentle contact with resins, the colour of effluent was reduced in all reactors except in control vials. Results obtained from the treatment of 100% effluent were presented in Figure 1, in which colour remaining after the treatment was plotted as a function of resin dose. IRA-458 and IRA-900 resins exhibited superior removal efficiencies to other resins, whereas IRN-78 showed moderate removal efficiency, and IRA-400, IRA-402 and IRA-410 showed the poorest efficiencies. Similar results were obtained when the diluted effluents were treated, but colour removal was completed at lower resin doses.

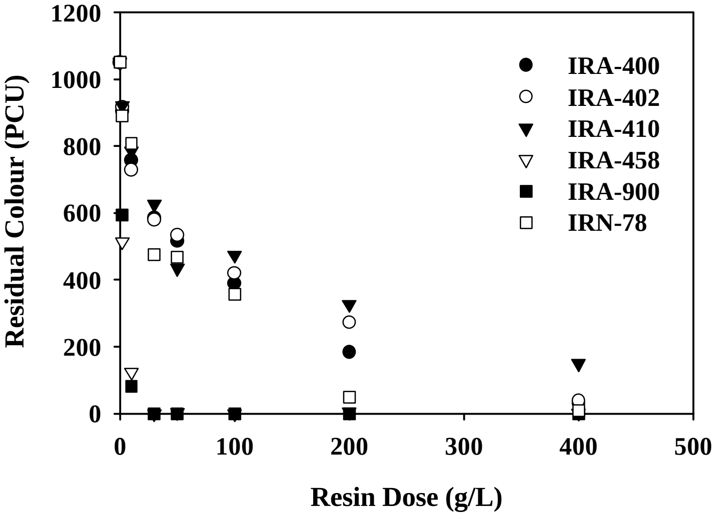

Figure 1. Decolourisation of pulp mill effluent with various strong base anion exchangers (Initial conditions: 1041 PCU, pH 7.9; 24 hrs of contact at 21°C).

Since ion exchange is a form of sorption from a solution, it is possible to describe the equilibrium of ions between the solid and solute phases by the Freundlich equation [1],

$$\frac{x}{m} = KC^{1/n} \qquad [1]$$

where

$x$ = amount of solute adsorbed (mol)
$m$ = mass of resin (g)
$C$ = concentration of solute remaining in solution at equilibrium (mol/L)
$K$ = the Freundlich constant (mol/g)
$n$ = the Freundlich exponent (dimensionless).

It is difficult to measure the concentration of individual colour-causing compound because pulp mill effluent typically contains a variety of those compounds. Therefore, in this case, a colour unit of samples, PCU, was adapted to the concentration of solute, although it is not a definite measure of concentration of colour causing compounds in the effluent. Since PCU represents a concentration, units of some of the parameters should be changed with regard to PCU unit. Thus the units of $x$, $C$, and $K$ are expressed as PCU·L, PCU, and PCU·L/g, respectively. In order to determine the Freundlich parameters, $K$ and $n$, the following linearlised form of the Freundlich equation [2] was used.

$$\log\left(\frac{x}{m}\right) = \log K + \frac{1}{n}\log C \qquad [2]$$

The result of isotherm analysis using the data in Figure 1 is presented in Figure 2 and Table 2.

Table 2. The Freundlich parameters for six resins.

| Resin | $K$ (PCU·L/g) | $n$ | Correlation const. ($r^2$) |
|---|---|---|---|
| Amberlite® IRA-400 | 0.089 | 0.84 | 0.72 |
| Amberlite® IRA-402 | 0.061 | 0.88 | 0.67 |
| Amberlite® IRA-410 | 0.0002 | 1.74 | 0.84 |
| Amberlite® IRA-458 | 10.5 | 0.50 | 0.98 |
| Amberlite® IRA-900 | 14.7 | 0.42 | N/A |
| Amberlite® IRN-78 | 0.62 | 0.55 | 0.71 |

N/A: not available due to too few data points

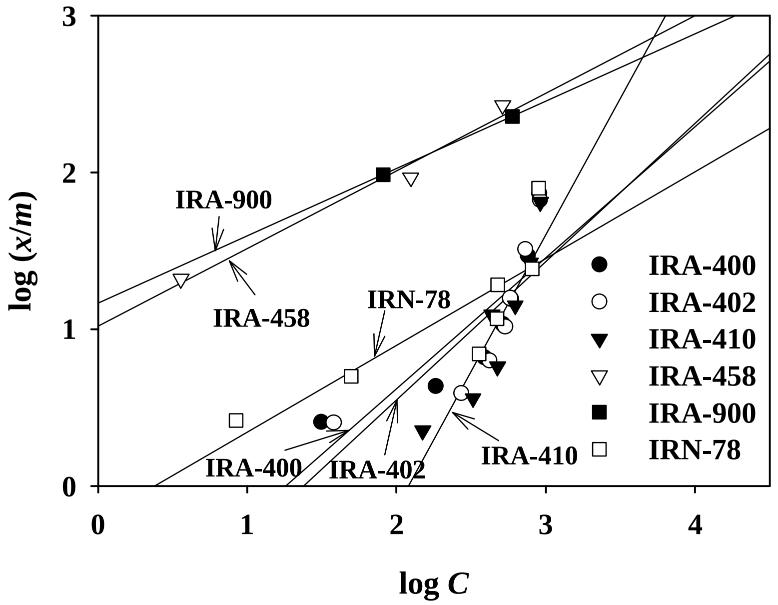

Figure 2. Linearlised Freundlich isotherms for six resins.

From the results shown above, IRA-900 exhibited the highest *K* value, which is a measure of the capacity of resin, of all followed by IRA-458. Again, IRN-78 showed a moderate capacity. IRA-400 and IRA-402 had lower capacity, and IRA-410 was the lowest. Therefore, the two resins, IRA-402 and IRA-410 were eliminated from further consideration.

## Colour and Chloride Removal from Pulp Mill Effluent Using Ion-Exchange Resins

Pulp mill final effluent was treated with three different doses (2, 20, and 200 g/L) of four types of resins (IRA-400, IRA-458, IRA-900, and IRN-78). The residual colour and chloride concentration were measured after the treatment. The results are presented in Figures 3 and 4. Colour was completely removed when more than 20 g/L of either IRA-458 or IRA-900 was used. Additionally, more than 85% of colour was removed after one day with all resins at the dose of 200 g/L.

Conversely, chloride concentration dramatically increased after the ion-exchange treatment except for the case of IRN-78, whose ionic form is hydroxide (see Table 1). This indicates that the chloride ions from the chloride-form resins were released into the aqueous phase during the colour removal. As shown in Figure 4, both colour-causing compounds and chloride were removed from the effluent by the hydroxide-form resin. This was accompanied by

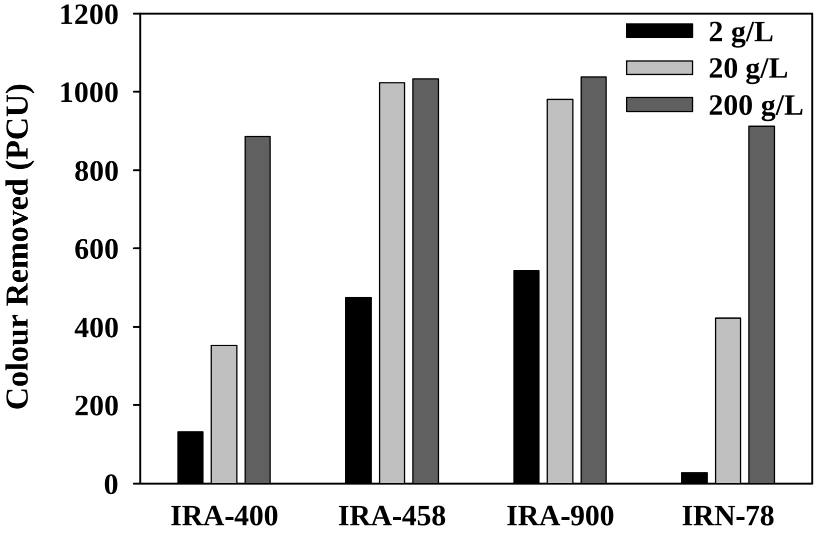

Figure 3. Decolourisation of pulp mill effluent with various strong base anion exchangers (Initial conditions: 1041 PCU, pH 7.9; 24 hrs of contact at 21°C).

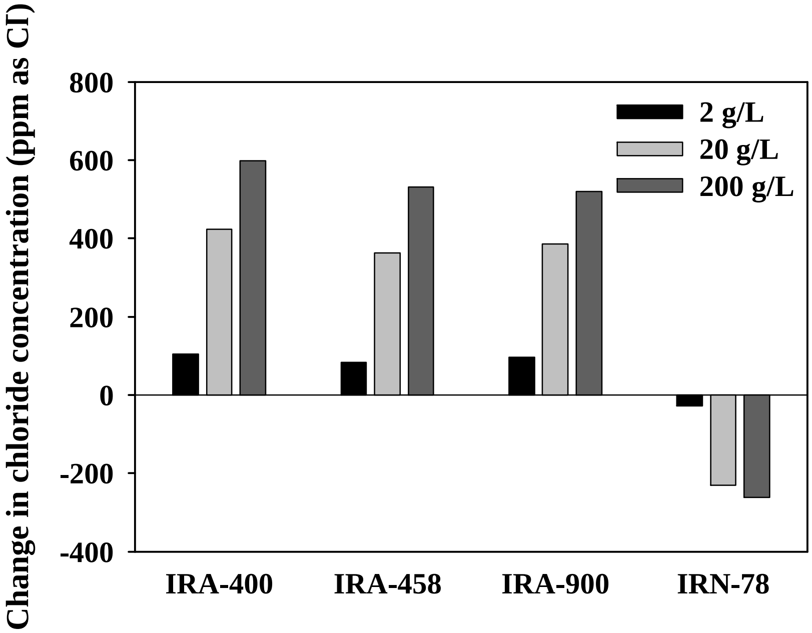

Figure 4. Effect of ion-exchange treatment on the chloride concentration of pulp mill effluent (Initial conditions: $[Cl^-]_0$: 264 ppm, pH 7.9; 24 hrs of contact at 21°C).

a release of hydroxide ions that was confirmed by increased pH values of treated effluent to around 10 and 11. The amount of chloride released was likely to correspond to the amount of colour removed; however, the ratio of chloride released to colour removed was greater for IRA-400 but lesser for IRA-458 and IRA-900. It should be noted that a small amount of chloride was detected in the control vials that contained pure water and a chloride-form resin even when the resin was washed with pure water prior to the treatment.

Since it was found that effluent colour was successfully removed either with IRA-458 or IRA-900, and chloride was also removed with IRN-78, a sequential treatment using two types of resins could be proposed as possible means to remove both colour and chloride from the effluent. As the colour removal stage, 1 L of final effluent was treated either with 100 g/L of IRA-458 or IRA-900 for one day at 21°C. Colourless solutions were obtained but the chloride concentration increased from 264 ppm to 752 ppm (IRA-458) and 749 ppm (IRA-900). The solutions were filtered through borosilicate glass fibre filters and cellulose membrane filters, and then treated with various doses of IRN-78 resin for one day to remove chloride. Only the results of the treatments using IRA-900 as a colour removal resin are shown in Figure 5 because of the similarity of results between two cases. It is observed that the chloride concentration was reduced with increasing amount of IRN-78 resin, and at a resin dose of 200 g/L, the chloride was completely removed. The pH values of all solutions were increased to around 10 and 11 after the treatment with IRN-78, which implies that the hydroxide ions on the resin were exchanged with chloride ions in aqueous phase.

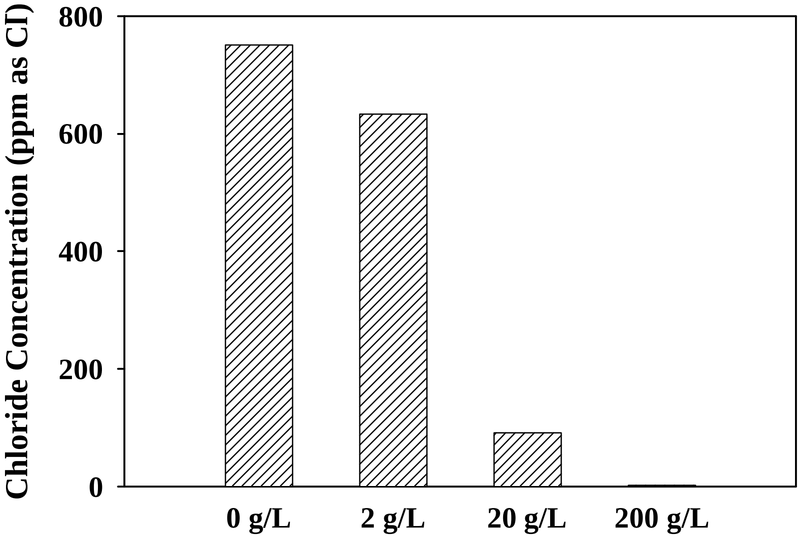

Figure 5. Chloride concentration after the treatment with IRN-78. Colour of the effluent was removed by the treatment with 100 g/L of IRA-900 prior to chloride removal (Residual colour: < 1 PCU, [$Cl^-$]: 749 ppm, pH 7.6).

During the treatment with IRN-78, a small amount of white colloidal precipitates were formed in all vials. The precipitates separated from the solution by filtration were completely dissolved with diluted hydrochloric acid. Since the similar colloid formation was observed as aqueous sodium hydroxide was added to the colourless effluent that had been treated with either IRA-458 or IRA-900 until pH values reached above 10, this phenomenon might be due to a metal hydroxide precipitation. Neutralisation of the basic solution with hydrochloric acid, again, led to the dissolution of precipitate. Interestingly, no precipitation was observed when the pH of original effluent was adjusted to the same pH range as above. This precipitation might cause a clogging problem when continuous flow columns were employed.

# DISCUSSION

## Screening of the Resins for Decolourisation of Pulp Mill Effluent

All six types of strong base resins tested were capable of removing colour from pulp mill final effluent, although the capacities varied with the resins. Amberlite IRA-900, which is the only macroreticular strong base anion exchanger tested, showed the greatest capacity of all resins tested here. It is well known that the macroporous structure of this resin allows capturing large size soluble organic molecules out of aqueous phase. Since chromophores in pulp mill effluent are likely to be derived from plant lignin, the molecules might be more effectively removed with this resin than others. Further research is required to examine other commercially available macroporous resins since only one resin was tested here.

Amberlite IRA-458 also showed a great capacity for colour removal. This resin has an acrylic polymer as a matrix structure, while the matrix of the other resins is styrene-divinyl benzene copolymer. The polyacrylic resins like IRA-458 are more hydrophilic than polystyrene-divinyl benzene resins and have generally greater affinity to natural dissolved organic carbon (Clifford 1990). Although regeneration of spent resins was not examined here, this type of resin would show good desorption characteristics as well due to its hydrophilic structure. Again, further research is required to examine other polyacrylic resins.

The rest of the resins including Amberlite IRA-400, IRA-402, IRA-410 and IRN-78, showed smaller capacities than the two resins discussed above. They were all styrene-divinyl benzene resins with similar physical characteristics. Although IRN-78 showed a better performance in colour removal than the other three, the calculated capacity ($K$ value in Table 2) was over 10-fold smaller than IRA-458 and IRA-900. IRA-410, the only type II resin used in this study, showed the lowest performance. However, it is not clear that the difference in functional groups causes this difference.

As previously stated, since a colour unit, which is based on spectrophotometric measurement, was used as a measure of the concentration of colour causing compounds in pulp mill effluent, the results of isotherm analysis shown here might not represent true capacities of resins and be possibly associated with a significant amount of errors. It should be noted that the type and concentration of effluent constituents would vary with time, wood types, pulping processes, as well as plant locations. Therefore, further research is required to confirm the applicability of this result to the effluents obtained from different mills and at different times of year. It may be necessary to determine the best resin for each of the effluents to be decolourised.

Since the selection of resin must be based on not only the removal capacities but also other factors such as regeneration and breakthrough characteristics of a target compound in packed column, further study should be done in a column where the solution to be treated is passed through the column.

## Colour and Chloride Removal from Pulp Mill Effluent Using Ion-Exchange Resins

While the colour of final effluent was successfully removed by all four resins tested, only Amberlite IRN-78 was able to removed both colour and chloride from the effluent. This result is not surprising because the rest of resins tested were used as the chloride form, where the chloride ions are exchanged with more preferable anions, which are colour-causing compounds in this case, and released to aqueous phase from the resin.

Two chloride-form resins, Amberlite IRA-458 and IRA-900, showed similar treatment results in both colour removal and chloride release. Although these resins were very effective in removing colour even at lower doses, the chloride concentration after the treatment increased to nearly triple of the initial. Since it is observed that more chloride was released when more colour was removed, the chloride release might become problematic if highly concentrated effluent was treated.

Amberlite IRA-400 showed the poorest performance in colour removal. Moreover, the ratio of the released chloride to removed colour was the highest of all. This implies that other organic or inorganic anions that do not contribute the colour of effluent or have lighter colour were preferred and exchanged with chloride ions on the resin. It is obvious that a variety of non-process anions present in pulp mill effluent such as sulfate, these anions may inhibit the colour removal when the resins with smaller pore size were used in this process. In other words, the complete demineralisation of effluent may not be achieved by the treatment with a macroporous resin alone.

## Comparison of Simultaneous and Sequential Removal of Colour and Chloride

Chloride was successfully removed with IRN-78 used either simultaneously with or subsequent to the colour removal. While it was still possible to remove chloride after the colour removal (Figure 5), there are several disadvantages of treating the effluent in the sequential manner. The first one is the chloride released during the previous colour removal stage. The concentration of chloride was increased substantially, to nearly three times of the concentration of the initial effluent in this study. As a result, more resin or greater bed depth of column may be required to remove chloride than in the case of simultaneous removal. The second disadvantage is the precipitation of white colloids observed during the treatment of colourless effluent with IRN-78. This is particularly undesirable when the effluent is treated with continuous flow column where the precipitate may cause a clogging problem. Since this precipitation is likely due to the reaction between hydroxide ion introduced into the aqueous phase during the anion exchange and some metal cations that already exist in the effluent, cation removal with cation exchange resin after the colour removal may prevent it. This cation removal can eventually be beneficial where on-site water reuse and plant closure is a final goal of the installation of ion exchange process.

Simultaneous removal of colour and chloride can be a cost effective method where a complete removal of those parameters is not necessary. Since only one hydroxide form resin was tested in this study, more hydroxide form resins must be examined to improve removal efficiencies. For example, the use of hydroxide form of macroporous resins or acrylic resins can be suggested. Since IRA-900 and IRA-458 have shown a promising ability of removing colour, conversion of ionic species from chloride to hydroxide with sodium hydroxide solution may provide an additional benefit. However, the different breakthrough characteristics between colour-causing compounds and chloride can be a problem when the simultaneous removal is employed in continuous flow columns. Additionally, as discussed above, the complete demineralisation may not be achieved with a single ion exchange process with a macroporous resin. Therefore, further research including column studies is required.

## CONCLUSIONS

This investigation has led to the conclusions outlined below.

### Screening of the Resins for Decolourisation of Pulp Mill Effluent

Six strong base anion exchangers including Amberlite® IRA-400, IRA-402, IRA-410, IRA-458, IRA-900 and IRN-78 were examined for the decolourisation of pulp mill final effluent. All resins were able to remove colour from the effluent. It was found that a macroreticular resin, IRA-900, and an acrylic gel resin, IRA-458, showed the best performance in colour removal of the resins tested.

### Colour and Chloride Removal from Pulp Mill Effluent Using Ion-Exchange Resins

The majority of the colour and chloride were successfully removed from pulp mill final effluent with a hydroxide form resin Amberlite® IRN-78. However, it was found that a substantial amount of chloride was released after ion-exchange treatment with chloride form resins. Although the released chloride ions could be removed altogether by a subsequent treatment with IRN-78, this may lead an increase in resin demand.

# RECOMMENDATIONS

Based on the results of this study, several areas have been identified for further investigation. These include examination of other resins for better performance, treatment of different effluents, regeneration of spent resins, and continuous flow column treatment. Investigation of the use of cation exchange resins for further demineralisation is also necessary for plant closure and waste stream recycle.

## Examination of Other Resins

It is suggested to examine more macroporous resins as well as acrylic resins for greater colour removal capacities. One of the possible candidates is Amberlite® IRA-958, which is a strong base anion exchanger with acrylic macroporous matrix. It is also possible to compare the resins manufactured by different companies.

For the chloride removal, more hydroxide form resins must be examined to compare their performance with that of Amberlite® IRN-78 tested in this study. It is also suggested to convert the ionic form of some resins, such as IRA-458 and IRA-900, from chloride to hydroxide for chloride removal. If the sequential treatment is selected to remove colour followed by chloride, it is necessary to identify the white colloidal precipitate observed during the chloride removal.

## Treatment of Different Effluents

Since the characteristics of pulp mill effluent may vary with mills, it is recommended to treat several different effluents to ensure the validity of the selected processes and resins. It is also suggested to treat combined effluent of different waste streams to determine a pH optimum for the process.

## Regeneration of Spent Resins

It is definitely necessary to examine the regeneration efficiency of spent resins because cost of regenerant is a major concern in the ion exchange process.

## Continuous Flow Column

All tests conducted in this study were batch test. However, for practical application of ion exchange, most of the tests must be done in a column where the solution to be treated is passed through the column. Since pulp mill effluent is a multi-component system, it is also important to determine the breakthrough profile for each target compound during the column operation.

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