

REFEREED PAPER

ENERGY FOOTPRINT AND OPERATING COSTS, A COMPARISON OF ION EXCHANGE RESIN AND ACTIVATED CARBON IN THE APPLICATION OF SUGAR DECOLOURISATION

HARDWICK JG AND HARDWICK EK

*Cwenga Technologies, Dunvegan, Johannesburg - South Africa**jenny@cwenga.com, ed@cwenga.com*

Abstract

Both ion exchange resin and activated carbon are well established technologies used in final stage decolourisation of sugar liquors for the production of high quality white sugars. These technologies are often seen to be in direct competition, but there are unique advantages and disadvantages to both, and they are applicable in different circumstances. This paper attempts to clarify the distinction. The colour removal mechanism between these technologies differ, resulting in slightly different colour causing molecules being removed and, as such, have been used as complementary processes.

Activated carbon is made reusable by thermal reactivation, a process that is highly energy demanding. The advantage of this is that there is no chemical addition to the process, and it can be run effectively as a zero liquid discharge system. This is in direct contrast to the ion exchange system, which in its traditional format requires very little energy to run. The effluent volumes produced by regeneration of ion exchange resin have been identified as a disadvantage of the technology. There has been research into the recovery and reuse of regenerant chemicals. This causes a reduction in chemical costs that is balanced with a rise in energy consumption by membrane and evaporation processes.

The key operating costs of energy footprint and chemical demand are compared, as well as secondary costs of effluent treatment and energy recovery systems applicable to both unit processes.

Keywords: activated carbon, ion exchange resin, decolourisation, energy costs, comparison study

Introduction

The first example of artificial ion exchangers being used on an industrial scale was in the sugar industry in 1901. An artificial zeolite was used to remove potassium from sugar juices (Harm *et al*, as cited in (Kumar & Jain, 2013)). It was only in 1951 that conventional ion exchangers were put to use in the treatment of sugar (McGinnis, 1951).

Activated carbon is a much older technology which started out as bone char although a date for when humans first discovered its use has not been determined. In 1794, it was found that activated carbon could be used to decolourise sugar and by 1805 all of Europe had adopted this technology in their refineries (Cecen & Aktas, 2012).

Technical Comparison

Both granular activated carbon (GAC) and ion exchange (IX) are well suited to secondary decolourisation, i.e. the purification step of dissolved sugar before crystallisation. In many new designs, activated carbon and ion exchange are viewed to be in direct competition to each other. There are a few other technologies that can be used for the final colour removal

stage, such as powder activated carbon, further carbonation, re-crystallisation, membrane processes, and oxidation techniques, but they are not considered in this paper. The focus is on GAC and IX because they are most commonly applied.

The compounds that make up the colour found in sugar vary greatly, including high (>2500 MW) and low molecular weight molecules, as well as polar and non-polar species. The mechanisms by which these colour compounds are removed has been reviewed by Davis (Davis, 2001) and included ion exchange and activated carbon, but also detail several other methods of decolourisation.

Activated carbon (AC) works by Van der Waals forces i.e. attractive forces between chemical groups in contact resulting from temporary dipole formation (Atkins, Overton, Rourke, Weller, & Armstrong, 2010), and as such have the ability to attract a very wide range of molecules. Most organic molecules found in sugar liquors are absorbed by AC to some extent, however, the force of attraction differs. Large, polarisable, aromatic and hydrophobic molecules are attracted more strongly to the activated carbon surface and are therefore particularly good for flavonoid, phenolic colourants, melanoidins and caramels (Davis, 2001) while sucrose is hardly attracted at all.

Ion exchange involves a combination of surface adsorption and electrostatic attraction to the functional groups and the polymeric backbone. Colourants mostly tend to be anionic and, when in contact with either a strong or weak base anion resin, form ionic bonds between the positively charged ionic functional group and the negatively charged part of the colour molecule. There is also an interaction with the matrix involving the Van der Waals effect between the styrenic pore structure and the aromatic groups of the colour bodies. Equivalently acrylic resins attract the aliphatic parts of the colour molecules.

In general it can be said that activated carbon is able to remove a greater proportion of the colour bodies that will ultimately have reported to the solid sugar crystal than conventional ion exchange. This is why a multi-step approach is often utilised as separate processes often remove different types of colour bodies. There are instances of IX and GAC working together. An interesting process of using both acrylic and styrenic resins in series to balance out the low fouling characteristics of the acrylic and the high colour removal abilities of the styrenic has been developed.

Operating Costs

The primary operating cost of both IX and AC is the replacement of the adsorption media. Activated carbon is topped up with every reactivation, while ion exchange tends to be replaced completely on a periodic basis. Despite the substantial difference in inventory size necessary to treat the same volume of sugar, and assuming that all other conditions are the same, the cost of media replacement lies within a similar range.

The table below details the operating costs for ion exchange and activated carbon based on similar inlet and outlet colour levels for comparison. In two cases the figures are idealised for a state of the art new plant, and the other cases are based on actual performances of plants in the Southern African region.

Table 1: Cost comparisons for ion exchange and granular activated carbon systems in Southern Africa

		GAC 1	GAC 2	GAC 3	IX 1	IX 2	IX 3
Dry substance	[°Bx]	65	65	62	68	68	65
Flow rate	t/ds/hr	55	25.7	143	25.5	25.5	55.2
Tons dry solids produced	TPA	435,000	203,544	1,132,560	585,684	600,000	435,600
Feed colour	lcumsa	800	1440	600	1000	1100	800
Designed outlet colour	lcumsa	200	385	120	350	600	200
Cost of makeup/solids produced		R14.94	R7.86	R15.01	R8.20	R7.00	R6.91
Cost of regeneration/ton of dry solids produced					R11.14	R6.23	R6.79
Cost of reactivation/ton of dry solids produced		R11.28	R15.85	R9.87			
Potential net saving using heat recovery/ton of dry solids produced		(R6.0)	(R6.0)	(R6.0)			
Cost of effluent treatment/ ton of dry solids produced					R12.08	R6.76	R6.72
OPERATING COST/TON DRY SOLIDS PRODUCED	R/t DS	R20.22	R17.71	R18.88	R31.42	R19.99	R20.42

Energy and chemical consumption

For activated carbon, the energy requirements of reactivation make up the next most significant cost, while for ion exchange it is the chemical consumption of regeneration.

Activated carbon

A number of different reactivation systems exist. For very large volumes multi-hearth furnaces are most commonly used. Fluidised bed and rotary kilns are also in use and show advantages in smaller scale operation.

Where a multi hearth furnace is used for reactivation of the activated carbon, often it is fuelled by natural gas. Because the price of gas can differ so greatly based on location, it can form up to half of the operating costs of running a GAC circuit. For comparison purposes a price of R5/kg was used.

Pollution control from a kiln system is often tailored to the regulations of the local area, and can differ greatly in design and cost. Often a low capital solution is put into place, but in cases where the "pollution control system is an after burner, it can contribute up to 40 % of the fuel bill" (Chou, 2000). Scrubber systems and sodium carbonate dosing systems are also sometimes required.

Methods for waste heat recovery have been investigated with great success. With the addition of a heat recovery steam generator (HRSG) or waste heat recovery boiler (WHRB) the net energy in the exhaust gas stream can be recovered to reduce the net energy

consumption by up to 60 %. The payback period on such a system is less than six months and should be considered for all new and existing refineries.

Ion exchange

Ion exchange resin is loaded with colour bodies during the service cycle, and once exhausted must be regenerated. Regeneration involves passing a brine solution that contains some sodium hydroxide through the resin bed. The high concentration of the regenerant solution increases the solubility of the colour compounds resulting in a separation from the resin. The waste regenerant is then sent to the general liquid waste of the sugar mill, or a recovery system. A counter-current regeneration can also reduce the chemical consumption and effluent volumes.

There have been a few important innovations with regards to ion exchange design that have made the regeneration volumes less of a concern, and have increased the lifetime of resins within the plant.

Styrenic resins are based on a crosslinked matrix of polystyrene. The functional groups are amines and these are attached to the phenyl groups of the backbone matrix. In strong base resins these are quaternary amines, while weak base resins are tertiary amines. Styrenic resins tend to have a stronger attraction to the colour bodies, and so produce a purer sugar product, but are more difficult to regenerate.

Acrylic resins are based on a crosslinked matrix of polyacrylamide. Functional groups are attached to the matrix through the amide linkages and are commonly quaternary amines. Because they have a lower attraction to the colour bodies they are more easily regenerated. This results in a lower use of chemicals and water, but generally has a higher colour leakage. The finer the particle size of the IX resin, the better the kinetics, however, fine resins result in high pressure drops across the bed. A new development is the use of resins with a narrow particle size distribution, which gives the benefits of both good kinetics and hydraulics.

Robustness of technology

Both IX and GAC are well established technologies for the decolourisation of sugar and remain the dominant techniques for final polishing. Both are able to handle the variation in the inlet colour from seasonal fluctuations. In the case of ion exchange there is an increase in chemical usage, and in activated carbon the media requires reactivation at a higher frequency resulting in increased energy costs.

Effluent treatment

The cost of liquid effluent treatment for activated carbon is very low and consists mainly of the removal of particulate matter before discharge. This is normally achieved by settling and simple filtration. The water can also be reused in the process.

With IX, the chemicals used in the regeneration process of the IX resin make up the main contaminants in the liquid effluent. For plants that are located close to large water bodies, especially the ocean (subject to permitting and local regulations), the discharge costs can be quite low. For inland plants where discharge is not possible, recovery of the brine is required and this adds to the capital and operational costs.

Regenerant recovery

Evaporation of the water from the brines can be used. The energy cost for evaporation per cubic metre of water removed is approximately R40. After evaporation a salt cake is obtained, which can sometimes be blended into cattle feed.

An alternative to evaporation is a membrane process involving nano filtration. Obtained costs for recovery of regenerant brine are expected to be lower than evaporation, in the region of R20 per cubic metre. There is still a concentrated brine to be dealt with from this process,

and if this can be reused for regeneration of the resin beds, it would make the ion exchange option more attractive.

Capital Cost Consideration

The capital costs of the plants are very site specific and comparisons are quite difficult to make. As a rule of thumb, however, ion exchange has a shorter contact time and therefore requires smaller media inventories, smaller diameter vessels, and a smaller overall footprint. (Ahring & Emeis, 2012)

Conclusions

The technologies discussed have their strengths and weaknesses. The final choice as to which technology is used depends on whether it is a new design or the retrofitting of an existing plant, its location and local regulations.

In general, ion exchange can be considered to be a lower cost operation where zero liquid discharge is not required. The costs of ion exchange become considerably higher where effluent treatment is taken into account. There is also the issue of the disposal of the concentrated colour bodies. Further testing of nano filtration could be of interest.

Activated carbon has a higher energy footprint and is therefore more sensitive to local energy costs. Where one or more sugar refineries exist in an area, economies of scale are possible by moving the spent carbon to a central reactivation kiln. Larger reactivation kilns tend to be more energy efficient and can also justify the extra capital costs of energy recovery systems.

Acknowledgements

The authors would like to acknowledge the support given by Nadja Hermsdorf of Lanxess, David Ormshaw of Chemviron Carbon, Chris Bryant of Jord, Ilya Krougly of AMS Technologies, Philip Mpesi of Illovo Malawi and Mano Moodley of Tongaat Hulett.

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