Coagulation with Recycled Magnesium plus Ferric Ion

An evaluation of the coagulation of lime-treated primary tank effluent was conducted because it appeared that, as influent water temperatures declined with the onset of winter, secondary settling tank effluent increased in cloudiness and floc could be seen passing over the effluent weirs.

The initial coagulation tests utilized *primary settled water* following the addition of lime. The pH of the lime-treated water varied only slightly around 11. In addition to the recycled magnesium ion, ferric sulfate was added to provide ferric ion as a coagulant aid. At the elevated pH, both magnesium and ferric hydroxides readily precipitate to form white and orange floc, respectively.

The results of the first jar tests indicated that magnesium hydroxide precipitation alone provided an acceptable degree of coagulation and settling. However, as in the secondary settling basin itself, there was evidence that a portion of the microfloc in the jar test suspension did not settle readily. The test water temperature was between 6 and 7°C.

The addition of 10, 20 and 30 mg/l of ferric sulfate resulted in progressively improved coagulation, floc settling and supernatant clarification. Combined with the magnesium hydroxide precipitate, each of the supplemental iron dosages resulted in a well-clarified supernatant.

These results indicate that the elevation of the concentration of magnesium ion resulting from the return of softening sludge may have diminished with decreased water temperature. Magnesium ion, 23 mg/l in the primary basin influent, increased by only 6 mg/l following the return, mixing and resettling of the recycled sludge. This marginal recovery of magnesium ion appears to be insufficient to yield an effective coagulant dose.

Even the subsequent addition of lime to raise the pH to 11 failed to result in significant precipitation of magnesium hydroxide. The lime-treated primary basin effluent increased in cloudiness as the result of calcium carbonate precipitation while only 6 mg Mg/l appears to have precipitated. After prolonged settling, the supernatant remained turbid and the settled material appeared largely granular.

Ferric sulfate ($Fe_2(SO_4)_3$) was added as a supplemental coagulant in an attempt to improve supernatant clarity. Each of the three trial dosages (10, 20, 30 mg Fe/l resulted in a clear supernatant. However, the acid produced by the hydrolysis of ferric ion in precipitating ferric hydroxide reduced calcium carbonate solubility marginally and increased the concentration of calcium ion in the supernatant. As the data indicate, the greater the ferric sulfate dosage, the harder the settled water. These results confirm the decision of Kansas City water to discontinue the supplemental feed of an acid-producing, inorganic coagulant.

The following photographs illustrate the comparative clarification of *lime-treated primary settling basin effluent* by magnesium ion alone and in combination with ferric ion.

Primary Basin Influent (control)	Primary Basin Effluent (after sludge return & settling)	Primary Basin Effluent + Lime (pH 11)	Primary Basin Effluent + Lime + 10 mg/l Fe	Primary Basin Effluent + Lime + 20 mg/l Fe	Primary Basin Effluent + Lime + 30 mg/l Fe
62 mg Ca/ l 23 mg Mg/l	49 mg Ca/ l 29 mg Mg/l	17 mg Ca/ l 23 mg Mg/l	26 mg Ca/ l 23 mg Mg/l	30 mg Ca/ l 25 mg Mg/l	40 mg Ca/ l 26 mg Mg/l
249 mg $CaCO_3$/l	242 mg $CaCO_3$/l	136 mg $CaCO_3$/l	158 mg $CaCO_3$/l	177 mg $CaCO_3$/l	199 mg $CaCO_3$/l

The carryover of magnesium hydroxide floc from the secondary basins in the Kansas City treatment process should have limited effect on filter influent turbidity since the secondary settled water is recarbonated and again settled in the final settling basins. Magnesium hydroxide that escapes the secondary basins may be expected to redissolve at the reduced pH created during recarbonation. This would increase the magnesium ion concentration and, thereby, the total hardness of the delivered water.

The final settling basins also provide additional time for precipitation of calcium carbonate.

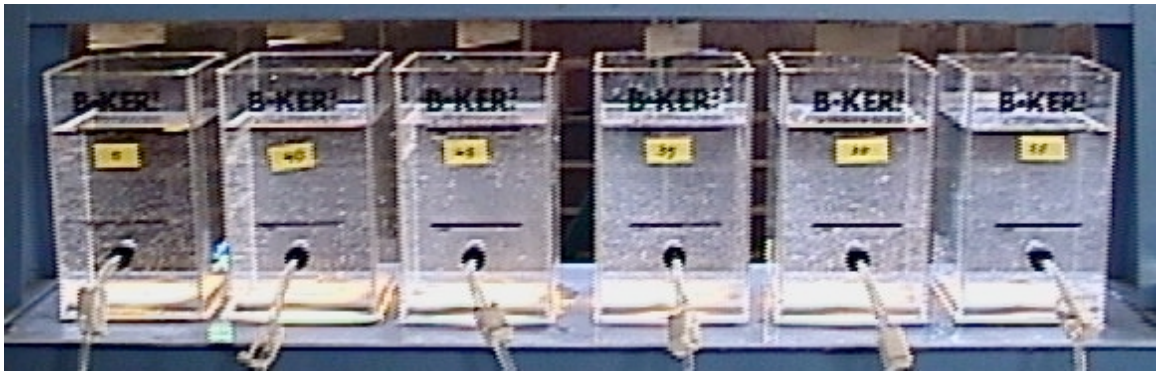
Effect of Solids Recycle

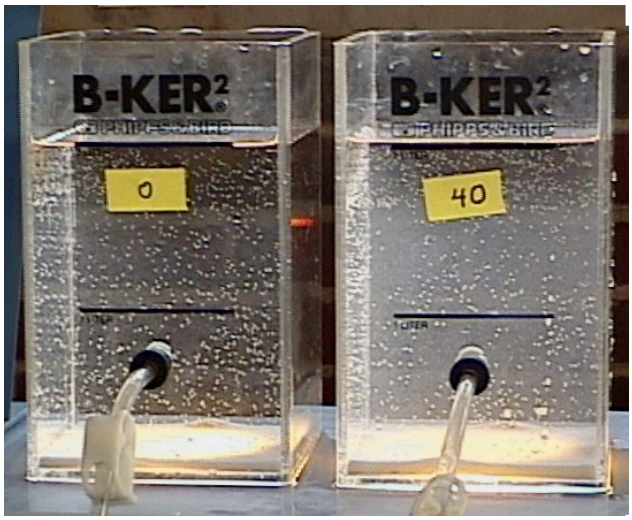
Solids recycle occurs in the mixing zone of the primary clarifiers. Different solids concentrations may be obtained depending upon softening sludge density, primary influent and recycle rates. For a time, a portion of the solids were returned to the flume along with the lime feed.

To evaluate the influence of returning solids to the flume, jar test studies were conducted with added dosages of return sludge ranging from 0 to 40 mg/l. No improvement in the rates of coagulation or sedimentation was observed. Instead, the turbidity of each settled water sample increased with the dosage of return solids.

The observed turbidity increase was due to the added suspension of calcium carbonate and magnesium hydroxide. This suspension did not aid in the coagulation of the lime-treated primary effluent. The results would indicate that, if return solids are added after the addition of lime, magnesium hydroxide will not have as great an opportunity to return to solution as it would have at the lower pH of the primary influent. In the supernatants from the six trials, illustrated below, magnesium ion ranged from 7 to 9 mg Mg/l and calcium ion from 42 to 52 mg Ca/l.

Again, these results support the decision of Kansas City Water to discontinue the return of softening sludge to the flume.

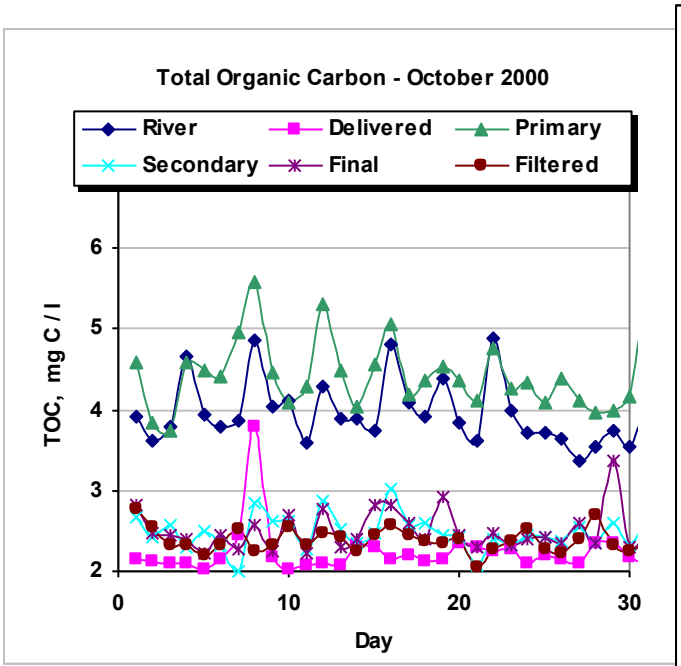


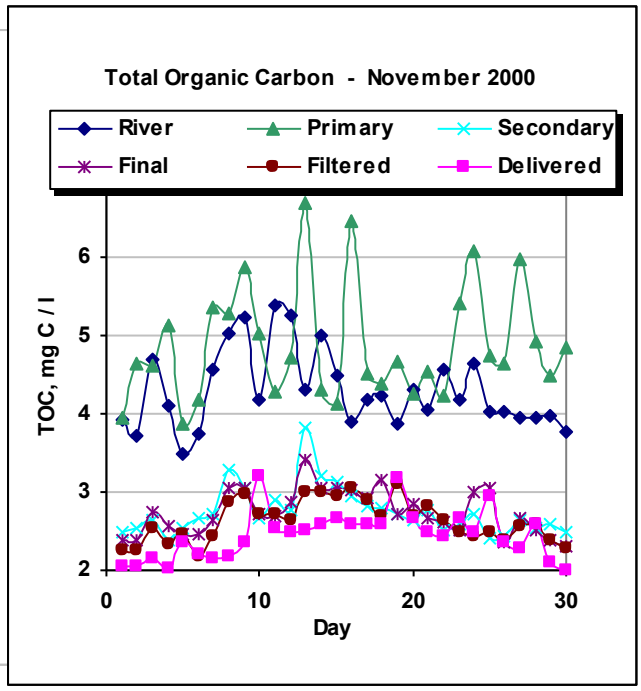


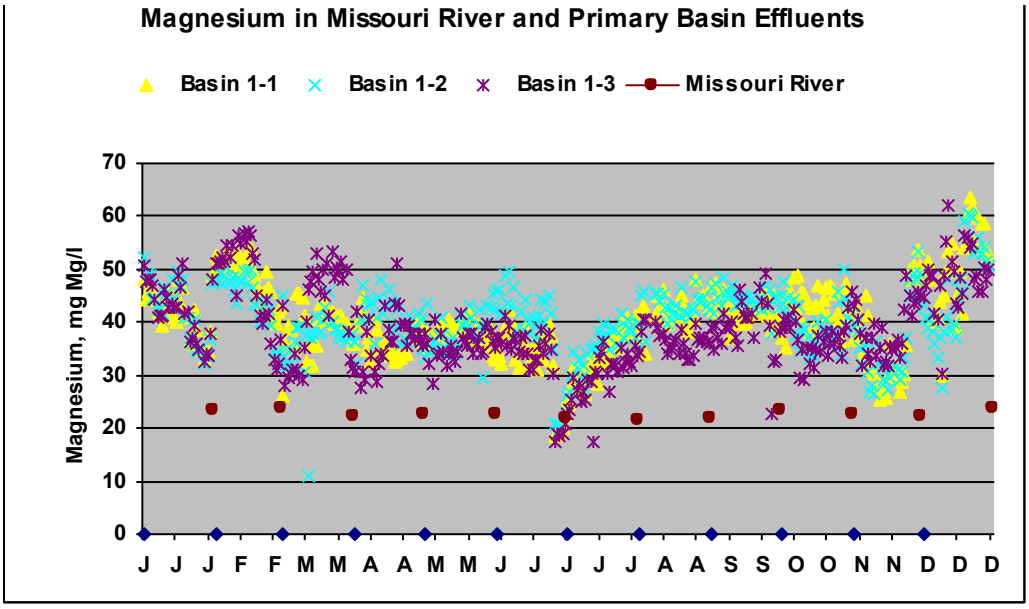
TOC Removal and Recycling

Examination of Kansas City Water's extensive database on total organic carbon (TOC) reveals a potential disadvantage in recycling softening sludge to the primary basin influent. As an example, in the month of October 2000, primary basin effluent TOC concentrations occasionally exceeded influent concentrations by as much as 1 mg C/l. The TOC increase through the primary basin averaged 0.48 mg C/l or 12%. Much of this increase may result from the return of particulate organic matter in the recycled softening sludge to the primary basin. The particulate portion of the primary effluent TOC should subsequently be removed in the secondary basin.

As expected, TOC removals in the secondary basins were substantial, averaging almost 2 mg C/l or 44% in October 2000. Further reductions in the final basins and on the filters, if any, were marginal. However, a further 10% reduction in average TOC concentrations was observed following disinfection and storage in the clear well (delivered water). It is not clear whether this last reduction is attributable to the oxidation of organic matter by the disinfectant.







In the absence of supplemental coagulant additions, the concentration of magnesium ion (Mg^{2+}, not total magnesium) in the effluent from the primary basin is critical to the subsequent coagulation, flocculation and sedimentation of the lime-treated water in the secondary basin. Data for the year 2000 shows that magnesium in the primary basin effluent varied seasonally. The lowest concentrations were observed in the summer months.

The amount of magnesium recovered as a recycled coagulant can be calculated as the difference between the primary basin influent and effluent concentrations. The Missouri River, which constitutes most of the primary basin influent, averaged 22.7 mg Mg^{2+}/l in the year 2000 whereas the primary basin effluent averaged 39.8 mg Mg^{2+}/l. Before accounting for the contribution of the well water, it appears that the average magnesium concentration increase was17.1 mg Mg^{2+}/l.

Analytical data for magnesium ion in the well waters, however, indicate that the blending of the river and well water has little effect on the primary basin influent magnesium ion concentration. The well waters averaged 23.7 mg Mg^{2+}/l as opposed to 22.7 mg Mg^{2+}/l for the Missouri River.

With daily variations in the return rates of recycled softening sludge, the increase in magnesium ion may be, at times, marginal or insufficient for effective coagulation.

Several determinations should prove useful for future plant operation with respect to coagulation. Magnesium dose-response curves for the coagulation of lime-treated primary basin effluent, performed over a range of temperatures, should be developed to bracket the Mg^{2+} concentrations that provide adequate particle entrainment and settling. In addition, operational methods that facilitate the control of magnesium ion following solids recycling should be codified so that, when magnesium concentrations are found to be inadequate, modified recycle or mixing protocols can be implemented.

Studies might also be conducted to determine the feasibility of utilizing an alternate or supplementary procedure for recovering magnesium ion from the softening

residues. Batch treatment of sludge with carbon dioxide should return high concentrations of magnesium to solution. This concentrated supernatant could then be returned to the primary basins to augment the magnesium derived from direct solids recycling. To further assess the feasibility of this procedure, the degree of return of organic carbon must also be considered.

Blending of Well and River Water

The Kansas City Water Department has the capability to blend Missouri River water with water from 14 alluvial wells. In addition to serving as a supplementary source, the well water is used to moderate water temperatures. This is particularly important in the winter when river water temperatures are close to freezing.

Well water temperature data for the year 2000, illustrate the cooling of the ground water in January and February. An exception was the temperature of Well #6 which increased from 48° to 59° Fahrenheit over this period. Otherwise, minimum well water temperatures (~40° F) were recorded in February. Generally, maximum temperatures (~74° F) were observed in September.