Studies of the Application and Removal of

Powdered Activated Carbon

at the City of Chicago Water Department's

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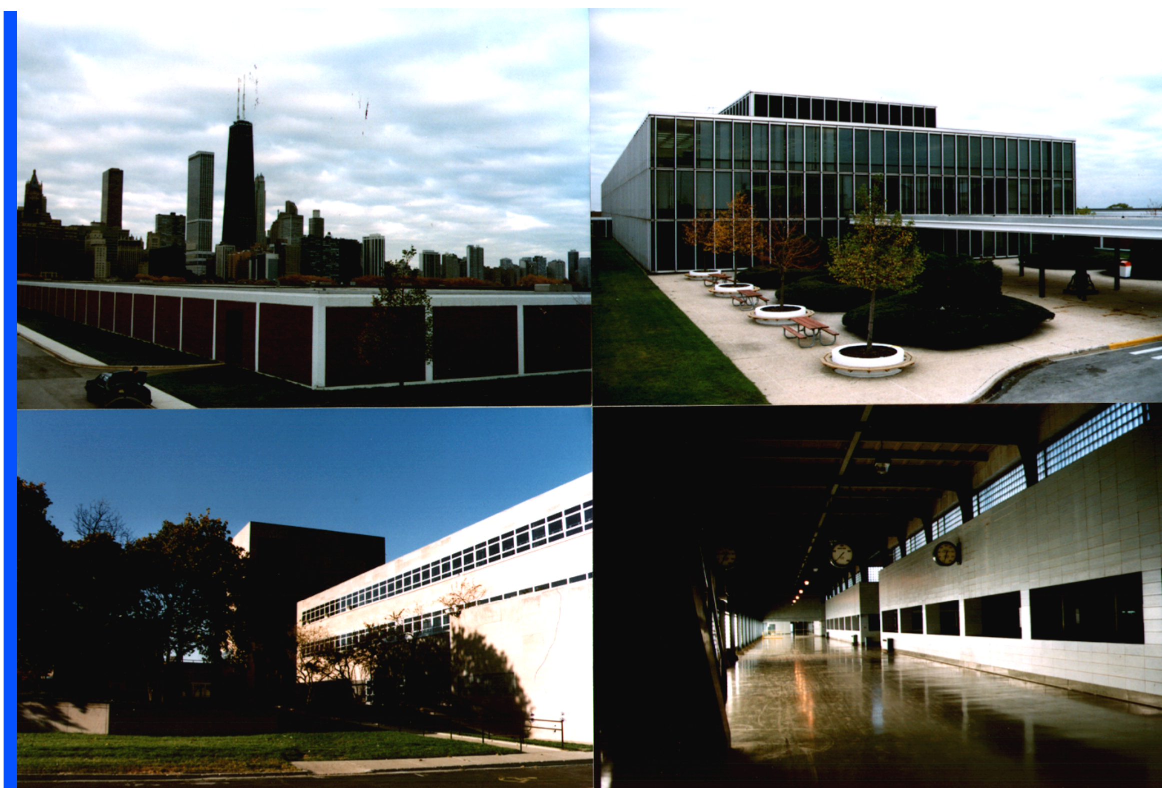
October 18 - 23, 1996



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Studies of the Application and Removal of Powdered Activated Carbon at the City of Chicago Water Department's Jardine and South Water Purification Plants

Background for the Study

The City of Chicago used less than 3000 kilograms (kg) of powdered activated carbon (PAC) in water treatment in 1992. However, in response to increases in 'taste-and-odor' complaints from consumers, PAC use was progressively increased to 876,000 kg (1993), 3,300,000 kg (1994) and 3,400,000 (1995).

In 1996, PAC applications were initiated in May and progressively increased to a maximum of 60 to 70 pounds per million gallons (8 mg/l) as water temperatures and odors increased. As temperatures declined, PAC dosages were reduced stepwise in 10 pound per million gallon increments and, ultimately, ceased at the end of October.

The present study was conducted in mid-October, 1996 when PAC feeds at the Jardine and South Plants were 10 and 20 pounds per million gallons, respectively. PAC is applied to Lake Michigan water in the mixing basins of both plants along with alum coagulant. After mixing, the waters are flocculated and settled, resulting in the early removal of a portion of the PAC applied. One of the objectives of the study was to determine the degree of removal of the PAC by alum flocculation and settling.

Following settling, additional solids removal is accomplished by sand filtration. Measurements made of PAC mass after settling and after filtration indicate the degree of removal of PAC on the filters at each plant.

Samples were taken for microscopic particle analysis from sampling lines from the respective rapid mix basins (Mixing Basin Effluent), settling tanks (Settling Basin Effluent) and after filtration (Clear Well). The samplings were repeated daily for five days; from October 18-22 at the Jardine plant and from October 19-23 at the South plant. Since the plants were attempting to feed PAC at a constant rate throughout this period, these samplings would be considered replicates.

PAC Feed Rate

It is notoriously difficult to maintain a constant feed of a slurry of powdered activated carbon. Plant data on the feed rates during the sampling period indicate that the mass of PAC fed to the respective mixing basins varied hourly throughout the day. These results, shown in *Table 1. Daily Variations in PAC Feed Rates at the Jardine and South Water Purification Plants*, confirm the the practical difficulties of feeding a powder to a large and varying water flow, even with hourly adjustment.

Table 1 indicates that, over a four-day sampling period, plant hourly feed rates varied by a factor of 2 to 5 times.

Table 1. Daily Variations in PAC Feed Rates at the Jardine and South Water Purification Plants (Range based on hourly measurements; Average calculated from PAC feed and plant water production.)

Date	Powdered Activated Carbon Feed Rates			
	Jardine Plant		South Plant	
	Avg., lb/mg	Range	Avg., lb/mg	Range
Oct. 18, '96	11	6-19	19	14-23
Oct. 19, '96	11	7-15	25	6-29
Oct. 20, '96	10	6-14	22	13-31
Oct. 21, '96	10	6-14	15	10-22

Settling of Large PAC Particles

In addition to the variations in feed rate, the data on PAC particle size distribution show that the PAC particles exhibit a wide range of particle size, ranging from less than 0.5 up to 35 μm in effective diameter. The PAC particle volume range may, therefore, exceed 320,000 times from the smallest to the largest.

The presence (or absence) of even a few large PAC particles in a sample can distort estimates of the total volume of PAC fed. In addition to constituting a disproportionately large share of the mass fed, the large PAC particles in the slurry feed are likely to settle readily during treatment as opposed to being transported through the settling basin and onto the filters. Larger PAC particles may also settle during sampling from sample taps. This PAC settling behavior is readily observed in jar test studies.

From the standpoint of effective PAC utilization, the PAC used in water treatment should be selected so that the largest proportion of the mass consists of particles 5 μm in diameter or less. The hydraulic (settling) properties of these smaller particles should ensure that they remain in suspension, at least, until flocculated and settled.

PAC Type and Densities

Dry PAC bulk densities may be on the order of 0.55 g/cc. However, when wetted, the particles exhibit a wetted density of about 1.38 g/cc. Wetted PAC particles will increase the aggregate density and enhance the settling of coagulant floc. Jar test studies show the effect of progressively increased PAC dosages on floc settling rates.

The Calgon WPH used at the Jardine Plant has an estimated wetted density of 1.4 g/cc. This is based on a composite of PAC density of 2 g/cc and pore water at 1 g/cc.

The South Plant uses Norit's Hydrodarco B which has a wetted density of 1.3 to 1.4 g/cc. In the present study, for the calculation of carbon mass from the measured volume of PAC per milliliter, a density of 1.38 g/cc was used.

Microscopic PAC Particle Counting and Sizing

The microscopic particle analysis conducted on the number and size distribution of PAC particles found in the thirty samples taken from the Jardine and South Water Purification Plants provide unique data. No comparable data have been reported in the waterworks literature.

The translucent nature of the alum floc formed during coagulation of Lake Michigan water allowed the enumeration and sizing of the PAC particles embedded in the floc as well as those particles which were free-floating. For visual reference, 37 micrographs (attached) were prepared showing particles in the influent Lake Michigan water as well as following the addition of the PAC at the mixing basin.

All micrographs were made using a Zeiss Axiophot light microscope. Some were photographed under ultraviolet light illumination. This highlighted fluorescent particles, such as algae, plus bacteria stained with the fluorochrome, acridine orange. Alum floc were evident from the aggregation of particles embedded in them. Virtually all of the particles present could be visualized using this method.

Other micrographs were taken under white light. The latter method was used for PAC particle counting since PAC particles are most prominent using this technique. The resulting micrographs show the dense black carbon particles against a light brown background. Other, more translucent, particles are not readily visible.

Particle Counts in Lake Michigan Water and their Removal During Treatment

On October 21, at the Jardine Plant, one milliliter aliquots of Lake Michigan water were passed through 0.2 μm neutron-track-etched polycarbonate membrane filters to recover the particles in the source water. The most abundant particles, small bacteria, both planktonic and particle-associated, can be seen on the enclosed micrographs. With a raw water turbidity of 3.96 ntu, 3,880,000 bacterial cells per milliliter were enumerated. In addition, 12,840 algal cells and 1,380 diatoms per ml were counted. There were a total of 12,431 particles per ml larger than 5 μm present.

On that same date, the Jardine Plant finished water was found to have a turbidity of 0.08 ntu; a bacterial cell count of 93,000 per ml (97.6% reduction) and 21 algal cells per ml (99.3% reduction). The 14.7 PAC particles per ml in the finished water were, of course, not initially present in the Lake Michigan source water.

Measurement and Calculation of PAC in Mixed, Settled and Filtered Water

While the membrane filtration of 5 ml aliquots were adequate for the enumeration of PAC particles in the mixed and settled water, large volumes of finished water from the clear well had to be membrane-filtered to obtain a sufficient number of particles for microscopic enumeration.
Large volume glassware (four-liter side-arm vacuum flasks) were purchased to allow the filtration of up to 54 liter portions of the finished water.

For the determination of the PAC, all samples were passed through 1 μm membrane filters. After enumeration of the total number of PAC particles present, particle size distribution was determined using a microscope reticle which had 5 μm gradations. Particles were sized along a continuous strip until 100 particles or more were sized.

The estimated diameters of the particles were then converted to equivalent spherical volumes. The total volume of the particles in each size distribution for each sample were then calculated, as shown on the attached tables for both the Jardine and South Plant samplings.

On separate tables, the volume of the average particle sized was calculated using the total volume and the number of particles sized. This average, in μm^3/particle, was then multiplied by the total number of particles enumerated per ml in that sample. The result yielded the total volume of PAC found per milliliter of sample (μm^3/ml).

Finally, taking the specific gravity of PAC as 1.38, the mass concentration of PAC was calculated as μm^3/ml x 1.38 $\mu g/\mu m^3$ = mg/l PAC. For the clear well samples, the results are expressed as μg/l PAC.

Interpretation of Results - Jardine Water Purification Plant

Of the 1.2 mg/l (10 pounds per million gallons) of Calgon WPH PAC applied at the Jardine plant, an average of 0.50 mg/l (42% of the nominal applied dosage) was observed in the effluent from the mixing basin sample line. These results indicate that sedimentation may have occurred in the sampling line used to obtain the water from the mixing basin. Alternately, since the analytical results were so similar, this line may actually sample settled water.

In addition to the low mass concentration of PAC observed, turbidity measurements on samples from this line were significantly (75%) lower than those observed in the raw Lake Michigan water. Instead, the turbidities measured were quite similar to those observed for the samples taken from the settled water sampling line.

Turbidities in the mixing basin would be expected to be the highest at this point in the the plant treatment process since the influent water turbidity is augmented by the coagulant and PAC feed. This is evident in the turbidities measured at the South Plant.

Based on these measurements, the authors believe that the Jardine Plant samples labeled ‘Mixing Basin’ and ‘Settling Basin’ may be from the same source since both the turbidities (0.85, 1.08 ntu) and PAC concentrations observed (0.50, 0.49 mg/l) are similar. If the influent PAC was 10 pounds per million gallon, the percent removal of PAC by sedimentation was approximately 95%.

The removal of PAC by filtration appears to be less ambiguous. The settled water PAC concentration of 0.49 mg/l is reduced to 0.887 µg/l in the clear well for a 99.82% reduction. Much of this removal occurs because the PAC in the filter influent is embedded in alum microfloc and is removal along with the microfloc. The efficiency of the direct removal of the carbon particles themselves was not determined in this study.

Interpretation of Results - South Water Purification Plant

An exceptionally wide range of PAC concentrations was observed in the South Plant mixing basin samples. However, the average concentration measured, 17.6 mg/l PAC, exceeds the nominal 2.4 mg/l PAC applied at the mixing basin. This may be due, in part, to the fact that Sample #2 contained several exceptionally large particles

(20 to 35 µm) which skewed the average size of the PAC observed. Elimination of Sample #2 reduced the indicated dosage to 4.3 mg/l. This dosage was used in calculations of the South Plant PAC removal efficiency.

The reduction of the PAC mass concentration to an average of 0.09 mg/l in the settled water would indicate highly effective coagulation and settling. The efficiency of coagulation and settling appears to be 97.91%. There appears to be relatively little PAC 'carryover' to the filters. As might be expected, the mass concentrations of PAC measured after settling appear to be more consistent than in samples derived from the mixing basin.

Again, at the South Plant as at the Jardine Plant, removal of the residual PAC on the filters appears to be substantial with a further 99.1% reduction in the PAC mass concentration applied to the filters. Overall, settling plus filtration appear to result in a 99.98% removal of the carbon applied at the mixing basin.

PAC Particles in the Finished Water

Of the PAC particles found in the finished water samples, approximately 95% were particles 3 µm or smaller. Such small particles provide little surface area for attachment of bacteria or larger organisms. The likelihood of these PAC particles providing such organisms protection against disinfection would appear to be small.

Assuming only particles larger than 3 µm might provide protection against disinfection, approximately 1.4 PAC particles per milliliter in the finished water would be considered particles of potential health significance.

The potential for the attachment and protection of virus particles was not been determined. However, a direct microscopic enumeration procedure for total virus particles has been published and confirmed in recent years. This scientific advance has now made it possible to assess virus particle removal by water treatment processes. In addition, it should be possible to assess the potential for protection of virus by particles in finished waters using epifluorescent microscopy.