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Project Summary

Reactivation of Granular Carbon in an Infrared Traveling Belt Furnace

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An all-electrical Shirco* carbon regeneration furnace and its air pollution control system were evaluated for cost and process effectiveness in carbon reactivation at the Pomona Advanced Wastewater Treatment Research Facility. The pilot scale Shirco furnace was operated within the range of 102 kg/d (224 lb/d) to 195 kg/d (434 lb/d).

The Shirco carbon regeneration system was as effective as the multiple hearth and rotary kiln furnaces in reactivating the exhausted granular activated carbon. The Shirco furnace required less operational skill but more maintenance labor than the multiple hearth or rotary kiln furnaces. The high maintenance requirement of the Shirco furnace was caused mainly by premature deterioration and breakdown of the heating elements and conveyor belt mistraction inside the furnace.

A cost estimate based on a typical regeneration capacity of 182 kg/h (400 lb/h) has been made for the Shirco furnace regeneration system. Comparison of this cost estimate to those that were reported for the multiple hearth and rotary kiln furnaces indicates that capital cost for the Shirco furnace is lower than that for the multiple hearth furnace and higher than that for the rotary kiln regeneration unit. The operation and maintenance cost for the Shirco furnace was, however, higher than those for both the multiple hearth and the rotary kiln furnaces. The overall process cost for the Shirco furnace system based on the operation and maintenance of the pilot unit was estimated to be 61.8 ct/kg (30.9 ct/lb) for the carbon regenerated.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Introduction

This study was conducted to evaluate and determine the cost-effectiveness of the Shirco infrared traveling belt carbon regeneration system. It was a portion of a much larger investigation into the removal of potentially hazardous trace organics from wastewater.

An extensive pilot plant study on the granular activated carbon adsorption process for wastewater treatment has been jointly conducted since 1965 by the Sanitation Districts of Los Angeles County and the U.S. Environmental Protection Agency at the Sanitation Districts' Pomona Advanced Wastewater Treatment Research Facility in Pomona, CA. Initially, the Pomona carbon study utilized a multiple hearth furnace system for carbon regeneration during the first 10 yr of pilot plant operations. During this period, the study concerned itself with the evaluation of the various treatment process parameters, mainly pretreatment requirements, carbon characteristics, hydraulic loading rates, adsorption capacity, backwash requirement, and mode of regeneration. Different types of carbon regeneration furnaces were not evaluated, since during that initial period the multiple hearth furnace system was very effective and reliable in regenerating the spent activated carbon in wastewater treatment processing.

However, because carbon regeneration is a major factor in the cost of activated carbon treatment, investigation of other regeneration systems was deemed desirable. A study at this site with a rotary kiln (a less capital intensive process) was reported previously. An investigation of the Shirco furnace was conducted because it uses a different method of contacting the heated regenerant gases with the carbon, which could yield lower loss of carbon during the regeneration cycle. In addition, the use of electricity for heat production by the Shirco furnace may be advantageous in certain locations.

Granular activated carbon (Filtrasorb 300) was exhausted by exposure to secondary effluent in a downflow carbon contactor and then regenerated in the Shirco regeneration furnace. The performance of the carbon after regeneration was evaluated by its adsorption capacity and efficiency in the next adsorption cycle. This process was repeated for several cycles, and after each regeneration, carbon quality was compared to that of its virgin state. The performance of the electric Shirco furnace was compared to that of the multiple hearth and the rotary kiln furnaces that were used in the past to regenerate the same type of carbon from the same carbon contactors and exposed to the same activated sludge plant effluent.

The ability to regenerate carbon to its pre-exhausted conditions, the ease of control and operation, the extent of carbon losses, and energy consumption were the basis for this evaluation.

Carbon Regeneration System

The infrared traveling belt carbon regeneration furnace system was manufactured by Shirco, Inc. The regeneration furnace is a rectangular, horizontal sy tem consisting of an insulated enclosu through which the carbon is transport on a continuous woven wire convey belt. This system was assembled from series of three modules that were bolt together before conveyor belt installatic (Figure 1) with the final dimensions 0.81 m (32 in.) wide by 3.4 m (135 ir long and a height of 0.86 m (34 in.). Th stainless steel modules were factory line with a thermal-shock-resistant, ceram fiber blanket insulation system and we equipped with support rollers for th conveyor belt. The Shirco furnace syste had a rated total regeneration capaci range of 327 kg (720 lb) to 381 kg (840 l of granular activated carbon/24 h of co tinuous operation.

Spent carbon is automatically release into the furnace feed hopper where it mixed with water by a small variabl

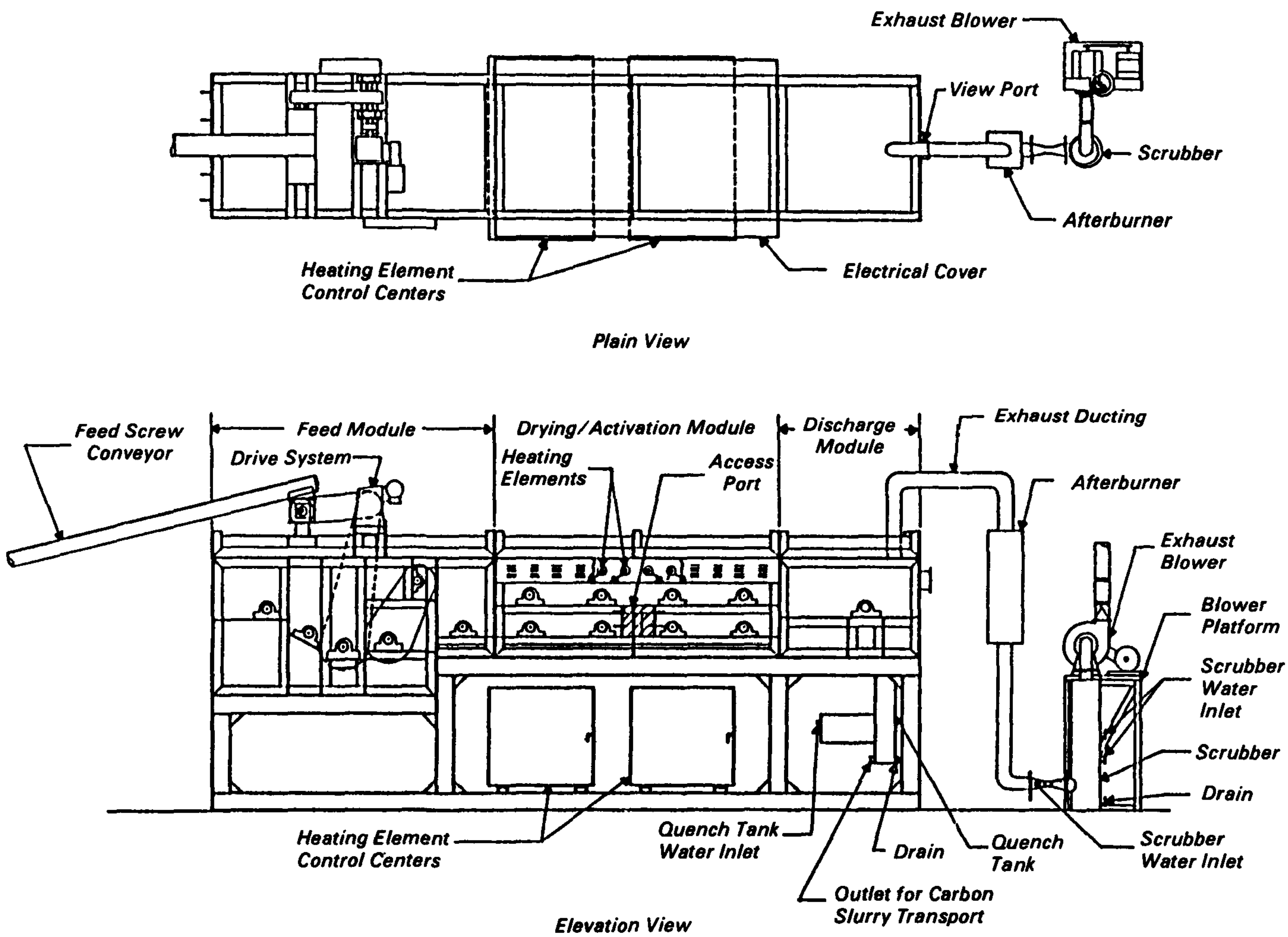

Figure 1. Shirco furnace regeneration system.

speed vibrator. The mixture of water and carbon is fed into the regenerator by a variable speed, spiral type, hollow, stainless steel screw conveyor. Inside the furnace, the wet carbon on the conveyor belt is leveled by an internal roller into a layer approximately 1.9 cm (3/4 in.) thick spanning 2/3 of the width of the belt. The carbon then moves through the various heating zones to accomplish the regeneration process. The required regeneration temperature is provided by 24 silicon carbide heating elements located approximately 15 cm (6 in.) above the carbon layer. The regenerated carbon is then discharged at the exit end into a quench tank for cooling before transport to the adsorption contactors.

The Shirco furnace is equipped with an afterburner and venturi scrubber unit for air pollution control of the exhaust gases. The required heat energy in this unit is provided by a cluster of 12 shorter silicon carbide heating elements on the top of the unit. After being cooled down to approximately 32°C (90°F) by the venturi scrubber, the burned air-exhaust mixture is dispersed into the atmosphere through a stainless steel stack by an exhaust blower.

Carbon Adsorption

During the Shirco carbon regeneration study, unchlorinated and unfiltered secondary effluent from the Pomona Water Reclamation Plant was treated directly by the carbon adsorption system. The Pomona Water Reclamation Plant is a 0.44 m^3/s (10 MGD) activated sludge plant, and is located adjacent to the research facility where this study was conducted. The three contacting carbon columns were operated in series in a downflow mode at a constant rate of 6.3 L/s (199 gpm) thereby providing a hydraulic loading rate of 2.4 $L/s/m^2$ (3.5 gpm/ft^2) and an empty-bed contact time of approximately 10 min for each column. The first carbon bed was backwashed daily with unchlorinated secondary effluent to maintain good hydraulic conditions for operation. A portion of the carbon treated water was stored and provided a sufficient amount of water for backwashing the second and third columns in the series every 2 and 4 wk, respectively.

The carbon contacting columns were taken off stream after they had treated a total volume of 32,200 m^3 (8.5 MG) of Pomona Water Reclamation Plant secondary effluent during the first adsorption cycle and approximately 41,600 m^3 (11.0 MG) during the three cycles that followed. The breakthrough of trace organics under study occurred during this 3 mo of operation, and the COD removal efficiency of the carbon columns usually leveled off at this point. The spent carbon was thoroughly backwashed before being hydraulically transferred to the elevated dewatering chamber.

Carbon Regeneration

Carbon retention time in the furnace was set at 18 to 35 min, depending on the extent of carbon exhaustion and operating temperature of the Shirco furnace. The regeneration temperature was maintained at 760° to 815°C (1400° to 1500°F) in the first (drying) zone and 899° to 955°C (1600° to 1750°F) in the second zone. This particular temperature range was chosen since the previous regeneration furnaces tested at this site operated in a similar mode. These temperatures were also recommended by Shirco, Inc., who uses a similar unit at their own research facilities. In general, during the first and second regeneration cycle the carbon in the final column was regenerated under lower temperatures than the carbon in the first column. The carbon in the first column, however, was regenerated under higher temperature since it was spent to a higher degree than the other two columns in the series. A controlled oxidizing atmosphere necessary for the carbon activation process was obtained by the steam generated in the drying zone and flow co-current with the carbon through the length of the furnace. The regenerated carbon was discharged from the Shirco furnace into a quench tank and was continuously educted back into the contacting columns.

Four adsorption and three regeneration cycles were conducted during the study, and appropriate samples were taken for evaluating the carbon adsorption and carbon reactivation efficiencies. In the course of carbon regeneration, a numbr of control tests measuring such parameters as apparent density, iodine number, molasses number, and methylene blue number, were performed to regulate the regeneration process and monitor the quality of the regenerated carbon. In general, approximately 550 h was required for each cycle resulting in the regeneration of 4,756 kg (10,500 lb) of carbon. Laboratory analysis on regenerated carbon was performed on an hourly basis for apparent density, every 2 h for molasses and iodine numbers, and once every 8 h for methylene blue number. Grab samples of spent carbon collected during carbon transfer and the hourly samples of regenerated carbon were composited over the regeneration period. These composited carbon samples were analyzed for apparent density, iodine, methylene blue and molasses numbers, and ash content.

Performance Of Regeneration System

During the initial shakedown operation of the Shirco carbon regeneration system, a number of mechanical difficulties were encountered. These problems were traced to inadequate design of portions of the regeneration system. The problems were generally in the areas of the carbon feed system, leveling roller, carbon movement through the furnace (sudden stopping of the belt), faulty tracking of the belt inside the furnace, furnace and afterburner temperature control, and temperature monitoring and recording instrumentation. A number of system modifications were performed, and most of the problems were corrected before the first carbon regeneration cycle. Some problems, however, were major design problems that could not be corrected at the research site.

In the course of thermal regeneration, the organic pollutants on the surfaces of the external and pore areas of carbon are oxidized and removed. This oxidation process, however, does not completely remove the adsorbed organics from the carbon pores. Therefore, a certain amount of the capacity is normally lost in every thermal regeneration cycle. In addition, the change of pore size distribution during the regeneration process may also contribute to the reduction of carbon adsorption capacity. The carbon adsorption capacity recovery was monitored by the determination of the iodine number, molasses number, and methylene blue number of both spent and regenerated carbons.

Iodine and molasses numbers are related to the surface area of the pores with a diameter larger than 10 and 28 angstroms, respectively. A continuing decrease in the iodine number with respect to regeneration cycle was apparent though the cyclic thermal regeneration was basically effective in restoring the operational adsorption capacity. The molasses number was found to gradually increase with each successive regeneration cycle. Since the molasses number is related to the surface area of the pores with a diameter larger than 28 angstroms, the increase in molasses number indicated an enlargement of micropore structures to macropore structures in the carbon during the repeated thermal regeneration process. This shift in pore size distribution also caused a reduction of total surface area of the carbon, which was indicated by the reduction of the iodine number. Methylene blue number is related to surface area of carbon pores with diameters larger than 15 angstroms. The methylene blue number of the carbon was not affected to the same extent as iodine and molasses number during the thermal regeneration.

The effects of the Shirco furnace carbon regeneration on the various carbon characteristic numbers as discussed above are similar to those reported for the multiple hearth study. Apparently, all three regeneration systems, the multiple hearth, rotary kiln, and Shirco furnace could repeatedly restore the carbon adsorption capacity equally well following each adsorption cycle.

Because of stretching and corrosive damage during regeneration, the conveyor belt required replacement after approximately 1,800 h of operation. Some of the heating elements had to be replaced after 550 h of operation. The entire 24 units of the heating elements in the furnace were replaced before the final regeneration. Since several of the new heating elements broke in half and became inoperative by the last days of final regeneration after operating for approximately 600 h, the average life of this component is estimated to be no longer than 750 h.

Cost Estimates

The cost estimates for the Shirco furnace system have been divided into two subcategories; namely, capital cost and operation and maintenance costs. The equipment cost consists of the carbon feed system, furnace system, and the air pollution control system, which consisted of an afterburner and venturi wet scrubber. The capital cost also includes the initial engineering cost, equipment shipping and installation cost, and contingency. The operation and maintenance costs include the utilities, operation and maintenance labor, carbon makeup, and maintenance materials consisting of heating elements and conveyor belt replacement. Costs are summarized in Table 1. Total estimated process cost is 61.8 ct/kg (30.9 ct/lb) of carbon regenerated.

Conclusions

The following conclusions can be drawn from the pilot plant study of the Shirco regeneration furnace and its comparison to the multiple hearth and/or rotary kiln furnaces:

- The all-electric Shirco furnace was found to be as effective as the multiple hearth and rotary kiln furnaces in reactivating granular activated carbon that had been exhausted by an activated sludge plant effluent.
- The Shirco furnace is insulated with a thermal-shock-resistant ceramic fiber blanket. Unlike the multiple hearth furnace's refractory lining, this type of insulation was able to withstand rapid startup and shutdown.
- The steam generated in the drying zone of the Shirco furnace moves co-currently with the carbon to ai the activation process; thus th auxiliary process steam used for th multiple hearth and rotary kiln fu naces was not required.
- The Shirco furnace system require less operational skill but more mair tenance labor than the multipl hearth and rotary kiln furnaces.
- The usable life span of the Shirc furnace components such as heatin elements and the conveyor belt wa much shorter than expected.
- The energy cost per pound of carbo regenerated by the Shirco furnac was higher than for the two othe furnaces studied previously. This i because of the higher cost of electri city to generate the same amount c heat energy produced by fossil fue for the multiple hearth furnace.
- All three regeneration furnace sys

Table 1. Cost Estimates for the Shirco Furnace Based on Operation of the Pomona Pilot Plar

Category	$(K)	$(K)	Ct/lb carbon
Capital			
Equipment			
Carbon feed system	25		
Furnace system	345		
Air pollution control system	125		
Total Equipment Cost		495	
Shipping and Installation		124	
Engineering		49.5	
Contingency		49.5	
Total Capital Cost		718	
Capital Amortization			4.87
Operation and Maintenance			
Utilities			
Power			11.7
Water			0.135
Labor			3.75
Carbon Makeup			4.9
Maintenance Material			
Heating elements			4.16
Conveyor belt			1.187
Other			0.208
Total Process Cost			30.91

tems required an afterburner and a venturi wet scrubber for effective emission control of air pollutants. However, since no fossil fuel is used in the Shirco furnace, the total exhaust gas volume was less.

- The average carbon loss for the Shirco furnace was slightly higher than 7%, which was reported for the multiple hearth and rotary kiln furnaces.
- The total capital cost of the Shirco furnace is estimated to be lower than that for the multiple hearth furnace and higher than that for the rotary kiln system. The total process and operation and maintenance costs for regeneration of carbon by the Shirco furnace were, however, higher than costs for the other regeneration systems studied previously.

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Irwin J. Kugelman *was the EPA Project Officer (see below).*
The complete report entitled "Reactivation of Granular Carbon in an Infrared Traveling Belt Furnace," (Order No. PB 87-209 466/AS; Cost: $13.95, subject to change) will be available only from:
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