

Study on Activated Carbon and Gold Recovery

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Abstract— Since the early days of 1920 large-scale activated carbon production in the large-scale activated carbon has steadily increased in importance to industry. Continual improvement and optimization of production processes and new raw materials have led to the advanced level of adsorption technology in use today Activated carbon lies at the heart of a number of different processes used in the industry. Environmental problems affecting air and water are solved through the use of activated carbon, and new applications are being continually developed in rapid succession. Of particular interest in the field of environmental protection is the reactivation and subsequent reuse of spent activated carbon and the recycling of activated carbon that is no longer amenable to regeneration or reactivation Granular activated carbon is a specific preparation of activated carbon, or activated charcoal. It has been used as a purification agent since antiquity. Activated carbon was used for drinking water filtration in ancient India, and as a multi-use purifier in ancient Egypt. In modern times, it was introduced to Europe's sugar refining industry in the early 19th century. Today, activated carbon in various forms, including granular, is used in a wide range of industrial, commercial, and home applications to remove contaminants.

Keywords: Pulverizing, Agglomeration, Activation, Adsorption, Desorption, Reactivation

I. INTRODUCTION

All forms of activated carbon are produced in the same way. Organic material with a high level of naturally occurring carbon, such as wood, peat, or coal is slowly heated in a low- or no-oxygen environment. This draws out water and impurities without allowing the material to burn. The resulting product is known as char. The char is then treated through a variety of chemical and physical processing methods to vastly increase its surface area and create a network of submicroscopic pores. The finished product, known as activated carbon, has a remarkable ability to attract and bind a variety of compounds. Activated carbon can be impregnated with various chemicals to improve its binding ability against targeted compounds.

II. ACTIVATED CARBON PRODUCTION

Activated carbons are produced from a wide variety of carbon-rich precursor materials such as bituminous coal, anthracite, sub bituminous coal, lignite, wood, coconut shells and peat. These materials are converted into activated carbon by either thermal or chemical activation processes. Thermal treatment typically includes steam gasification (activation) and chemical activation uses reactive inorganic additives at relatively lower temperatures. Activated carbons produced from bituminous coal can be classified as direct activated or reagglomerated. Direct activation involves sizing the coal to approximately the final particle size required and thermally

activating the sized coal. Direct activation can produce a less costly product compared to reagglomeration.

A. Reagglomeration

Reagglomeration involves first pulverizing and briquetting the coal with organic binders. The briquettes are stage crushed to achieve the desired particle size. Once the reagglomerated material has been activated, the binder is also converted to a graphitic structure that interconnects the activated coal particles. The hardness and abrasion characteristics of reagglomerated and direct activated GAC are often comparable. However, reagglomerated carbons tend to have a more homogenous pore structure that can be better for certain organic contaminant removal. During thermal treatment, all the carbonaceous raw material reacts by means of condensation reactions to form increasingly larger aromatic plate structures. The density of the structure is influenced by the characteristics of the raw materials. The denser the raw material, such as bituminous coal, the more extensive the structures will be. These extended flat graphite platelets are arranged randomly within the GAC particle to provide the extensive internal structure needed for adsorption to occur.

B. Adsorption on Activated Carbon

If an adsorbent such as activated carbon is brought into contact with an aqueous solution or a gaseous medium containing adsorbates, the adsorbate concentration of the medium is reduced as adsorbates accumulate on the activated carbon. After a sufficient period of time, a stationary balance will be achieved between the adsorbate concentration in the liquid or gaseous medium and the concentration on the adsorbent. This is known as adsorption equilibrium.

The degree of adsorbate accumulation on activated carbon in relation to the concentration of the same substance in the surrounding medium is referred to as adsorption capacity. The maximum achievable accumulation depends primarily on the characteristic properties of the adsorbent, the properties of the adsorbate substance and other physical and chemical conditions affecting the adsorption process. Adsorption velocity depends, among other things, on the type of activated carbon, pore size, pore radius frequency and distribution, the physical and chemical attributes of the adsorbate, the properties of the ambient gas or liquid phase and a number of process-related parameters. Adsorption speed diminishes with progressive saturation of the activated carbon.

C. Adsorption Kinetics

Adsorption equilibrium is not generated spontaneously, as adsorbate molecules must first be transferred from the solution to the adsorbent particle and then from the surface to the interior of the particle. The progress of adsorption over time until equilibrium is reached is referred to as adsorption kinetics.

In the fixed bed process, the medium to be purified flows through an adsorber filled with activated carbon and deposits adsorbate onto the activated carbon. As the adsorbate concentration in the medium decrease, the concentration on the activated carbon increases, forming a concentration profile in the adsorbent bed and a corresponding profile in the interparticle volume of the corresponding activated carbon bed.

As in all physical-chemical processes, equilibrium is eventually achieved between adsorption and its reversal
adsorption \leftrightarrow desorption,
which is described by the Freundlich Equation. Adsorption equilibrium is a function of temperature and also depends upon the properties of the adsorbate, the pH value and the type of activated carbon used.

In gas phase applications, lower temperatures favour adsorption; in the liquid phase, particularly in the treatment of viscous liquids, elevated temperatures are normally used in order to exploit the advantages of higher diffusion rates and lower viscosities.

The specific correlation between load concentration and residual concentration at a constant temperature for each specific adsorption process forms an isotherm, which is described mathematically in a number of different isothermic equations.

The Freundlich isotherm equation is used for virtually all isotherm descriptions of adsorption in liquid solutions:

$$Q = k * C^n$$

Where

Q ... quantity adsorbed

C ... residual adsorbate concentration in the liquid solution (mg/l; g/ccm; ml/ccm, etc.)

k, n ... constants

In the graphic representation of the adsorption isotherms, the experimentally derived equilibrium loads for various different concentrations are entered in a dual-logarithm coordinate system. If the Freundlich Equation applies, the curve is straight. This is the case for most substances within a given concentration range.

The exponent n expresses the incline of the straight curves.

In actual practice, liquids frequently contain several different pollutant substances. During adsorption, the different components compete for adsorption space on the activated carbon, often leading to over layering and displacement effects. As a result, the load capacity for the separate components is reduced during simultaneous adsorption of other substances. The more adsorbent the other substances are, the greater the reduction factor.

D. Reactivation

Charged or exhausted granular activated carbon can often be reactivated using a thermal process that is very similar to the original activation process. The activated carbon can then be reused. Thus reactivation is an economical and environmentally sound alternative to disposal.

A number of different technical systems can be used in the reactivation of activated carbon, including:

n rotary kilns

n multiple-hearth furnaces

n fluidized bed furnaces

Activated carbon passes through the following steps in the reactivation process:

n drying (up to 100° C)
n desorption and pollutant pyrolysis (100 – 700° C)
n activated carbon reactivation (watergas reaction) (above 700° C)



The pollutants released during the reactivation process are then incinerated at temperatures of up to 1.200° C. The flue gas is then scrubbed. The process sequence, which is adapted to specific application requirements and types of activated carbon, guarantees high reactivation quality. In most cases it is possible to restore the original adsorption capacity of the activated carbon.

III. ACTIVATED CARBON IN GOLD RECOVERY

Carbon has been traditionally used to recover gold from cyanide leachates, but recent technological advances have resulted in the use of resins as a highly efficient and cost-effective method of gold recovery. Fundamental aspects of gold recovery utilizing the Carbon-in-Pulp or Carbon-in-Leach processes. The purpose is to describe in simple terms what activated carbon is all about and how it adsorbs gold. The understanding of the mechanism of gold adsorption is important because the CIP/CIL processes work as a result of the gold adsorption mechanism, which is a chemical occurrence. Factors that affect the adsorption of gold are discussed. Finally, performance monitoring methods that help control the operation of the CIP/CIL process are discussed.

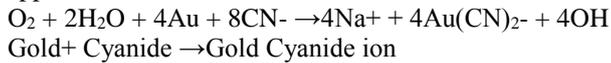
- 1) Macropores (500 to 2000 Å in diameter) these are the large pores that run from the surface of the activated carbon into the interior. The macropores allow for the rapid movement of adsorbates (species that will be adsorbed by the carbon, e.g. gold) into the activated carbon granules.
- 2) Mesopores (100 Å to 500 Å) these are the pores that branch off the macropores that serve to allow the adsorbates to leave the macropores
- 3) Micropores (8 to 100 Å) which are of the right size to allow the adsorbates to be strongly adsorbed by activated carbon. These pores generally occupy 95 % of the total internal surface area of activated carbon. It is within the micropores that adsorption takes place, however the meso and macropores are important because they facilitate the rapid transport of the adsorbates into the activated carbon.

A. Mechanism for Gold Adsorption

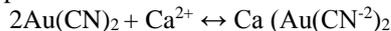
Gold is a noble metal, it prefers to exist in its natural state as gold metal. Very few metals are noble metals and noble metals are by nature unreactive. Cyanide is one of the few chemicals that will react with gold. In metallurgical applications, gold recovered is generally present in low grades thus must be "concentrated up" to an extent where it may be smelted into a bar.

Since practically all gold reserves are very low (up to 20 g/t ore) the gold must be concentrated up using methods that rely on a change of phase. It is much easier to "concentrate up" gold from the solution phase than from the

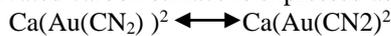
solid phase. Activated carbon is an adsorbent that increases the concentration of gold in the solution phase. For example, an ore containing 3 g/t is leached, mixed with carbon, which loads to 3 000 g/t, a concentration up of 1 000 times. Initially the gold is leached using cyanide, lime and oxygen. The mechanism for leaching of gold is complex and the exact mechanism is subject to argument, however, from the activated carbon point of view, the dissolution of gold from the ore results in gold present in water as the gold cyanide ion approximated as follows:



The stability of the ion pair between the Metal n+ and gold cyanide governs the selectivity for calcium, the gold cyanide ion joins with calcium to form a calcium gold cyanide ion pair:



The ion pair is a neutral species and this will be adsorbed, while the gold cyanide ion is charged, so activated carbon will not adsorb it. The adsorption of the gold ion pair onto the activated carbon surface is expressed as:



Since there is no reaction between the gold ion pair and the surface of carbon, the extent of adsorption is dependent on external factors. Perfect conditions do not occur in reality for adsorption, so an equilibrium is formed.

B. Desorption (Elution)

The adsorption of gold by activated carbon is controlled by a chemical phenomenon, driven by a series of factors. Inversely changing key factors that favour adsorption will reverse the adsorption mechanism. As discussed in section 6, the most stable ion pair formed for gold is the calcium gold cyanide ion pair. This ion pair is present on the surface of activated carbon due to physical adsorption. In order to elute gold off the carbon, the calcium gold cyanide ion pair must be changed into a form which the activated carbon will reject. i.e. the adsorption processes is reversed. This occurs in two steps:

- Firstly, in the presence of excess sodium ions, (in 3 to 5 % NaOH for example) the calcium is ion exchanged for sodium forming the less stable Na [Au (CN)₂] ion pair. This is caused by the concentration effect of excess sodium ions.
- The less stable Na [Au (CN)₂] is not stable at elevated temperatures and so breaks down into its composite ions Na⁺ and Au(CN)⁻² which carbon releases. This is the reason that heat is required during elution, the higher the temperature, the more effective the reaction.

$$\% \text{Selectivity of DBS} = (\text{moles of DBS formed} / \text{moles of BC converted}) * 100\%$$

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C. Factors Influencing Gold Adsorption onto Activated Carbon

The adsorption of gold is affected by a number of external factors that affect both equilibrium and kinetic adsorption.

The design and operation of an adsorption circuit will be governed by these factors:

- Mixing efficiency
- Pulp density
- Particle size of carbon
- Temperature
- Cyanide concentration
- pH
- Ionic strength
- Gold tenor
- Contact time
- Organic poisons
- Inorganic poisons
- Quality of activated carbon - Carbon activity- Elution grade

D. The Importance of Circuit and Activity Profiles

The gold adsorption process is defined and affected by external factors and the measurement and evaluation of this data aids in identifying and solving adsorption inefficiencies. If something changes in the adsorption process, the impact is generally negative, which reduces the gold solution value, i.e. the gold in solution tails increases.

In the counter current CIP and CIL or Carousel plants, the movement rates between carbon and pulp are different. The pulp moves continuously down the circuit whereas the carbon is moved up intermittently. The pulp would spend between 10 minutes (in a high intensity Pumpcell tank) to 4 hours (in a CIL tank), thus the activated carbon in each tank has a limited time to adsorb as much gold as possible, therefore adsorption kinetics plays a significant role. The carbon stage inventory or part thereof is moved once a day from tank to tank. This maybe via complete batches as in carousel circuits to continuous transfer in some CIP/CIL circuits. A constant feed in terms of pulp flowrate and gold concentration (which is normal for gold plants) will result in the activated carbon reaching an equilibrium between the gold on carbon and gold in solution in the tank. Since the tanks in the adsorption circuit follow each other, the independent equilibrium and kinetic performances for each tank follow suit, and can be related to each via other profiles. These profiles are:

- Gold-in-solution profile – This is the measurement of gold in solution phase in each tank. Comparing the values to each other should result in an extraction percentage averaging 60 % per stage throughout the circuit. This is a measurement of kinetics extraction.
- Gold-on-carbon profile – This is the measurement of gold-on-carbon in each tank. Comparing the values to each other should result in a reduction of 50 % per stage down the circuit. This is a measurement of pseudo equilibrium gold loading.

Examples of typical profiles for a CIP plant are as follows:

	Gold in Solution Profile		Gold on Carbon Profile (g/t)
	Extraction (%)	Value (mg/l)	
Feed		5.000	-
Stage 1	60	2.000	5 000
Stage 2	60	0.800	2 025
Stage 3	60	0.320	835
Stage 4	60	0.128	353
Stage 5	60	0.051	169
Stage 6	60	0.020	93
Stage 7	60	0.008	62
Eluted Carbon	-	-	50

If, something goes wrong in the process, and the stage extraction efficiency drops from 60 % to 50 %, the values change:

	Gold in Solution Profile		Gold on Carbon Profile (g/t)
	Extraction (%)	Value (mg/l)	
Feed		5.000	-
Stage 1	50	2.500	5 000
Stage 2	50	1.250	2 506
Stage 3	50	0.625	1 258
Stage 4	50	0.313	635
Stage 5	50	0.156	323
Stage 6	50	0.078	167
Stage 7	50	0.039	89
Eluted Carbon	-	-	50

REFERENCES

- [1] He Wenjie, Li Weiguang, Zhang Xiaojian, Huang Tingling, Han Hongda. Novel Technology for Drinking Water Safety[M].ChinaArchitecture&BuildingPress.2006
- [2] WeissenhornFJ. The Behavior of Ozone in the System and Its Transformation[J].AMK- Berlin, 1977, (2):51-57.
- [3] Parkhurst, J. P. et al. Pomona Activated Carbon Pilot Plant J. WPCF, 1976, 37(1).
- [4] Li Weiguang, Ma Fang, Yang Xianji, Zhao Qingliang, Wang Qingguo. A Study on Purification Performance of Biological Activated Carbon[J].Journal of Harbin University of Civil Engineering and Architecture, 1999, (32) 6: 105—109. (In Chinese)
- [5] Eberhardt M S. Untersuchunger Zur Berwendung Biologisch Arbeitender Ativkohle Gilter Bei Der Trinkwasseranf Bereitung[J].Wasser-Abwasser, 1975, 116(6): 29-34.
- [6] Sontheimer H. The Mulheim Process. J. AWWA, 1978, 70(7):62-68.
- [7] Greening F. Experience with Ozone Treatment of Water in Switzerland. In: Andrews G F,eds. Proceedings 8th Ozone World Congress.Zurich:IOA,1987,49-54.
- [8] Gomella C. Ozone Practices in France. J. AWWA, 1972, 64(1):41-45.
- [9] Tian Yu, Zeng Xiangrong, Zhou Ding. Development of Coordinating Technology for Ozonation and Biological Activated Carbon System [J]. Journal Of Harbin Institute Of Technology,1998,30(2):21-25.