Adsorption of Nonionic and Ionic Polyacrylamides on Hematite

B.M. Moudgil and P. Somasundaran

Abstract — Adsorption of a nonionic polyacrylamide (PAM), an anionic polyacrylamide with sulfonate functional groups (PAMS), and a cationic polyacrylamide with amine functional groups (PAMD) on hematite was investigated as a function of different solution conditions. Adsorption results indicate that the major mechanisms of adsorption of polyacrylamides on hematite is through hydrogen bonding, with electrostatic forces playing a secondary role. All the polymers exhibited irreversibility of adsorption upon dilution. Also, entropic effects were determined to be important in adsorption. Surface chemical properties of hematite and solution chemistry of the polyacrylamides are considered to explain the polymer adsorption behavior on hematite.

Introduction

Beneficiation of mineral fines using floc flotation technique depends on the adsorption of the polymeric flocculant only on the desired mineral component. One method of achieving selective polymer adsorption is by controlling the interactions between the polymer and the surfactants used as collectors. These interactions could not only modify the adsorption behavior of various molecular species on the mineral particle, but can also lead to precipitation, resulting in higher reagent consumption (Somasundaran and Moudgil, 1982). Precipitation can also adversely affect separation efficiency of the process. At present, effective separation of clays from sylvinite at Cominco in Canada is achieved commercially through controlled interaction between the polymeric and collector species. It would, however, be necessary to understand the mechanism of such interactions before this phenomenon could be successfully applied to beneficiate other complex ores. To study the principles that govern the effect of such interactions in mineral processing, effect of solution conditions on the adsorption of a nonionic polyacrylamide (PAM), an anionic polyacrylamide (PAMS-sulfonate functional group), and a cationic polyacrylamide (PAMD-amine functional group) on hematite was investigated.

Background

Adsorption of Polyacrylamides on Hematite

Adsorption of a polymer on a mineral surface is attributed to electrostatic charge attraction, hydrogen bonding, covalent bonding, or hydrophobic interactions. It has been reported that the principal mechanism for the adsorption of polyacrylamide type polymers on oxide minerals is through hydrogen bonding (Linke and Booth, 1959). Hydrogen is shared between surface oxygen atoms and oxygen or nitrogen of the polymer. Such adsorption will be influenced by any charge in the polymer backbone, anionic or cationic (by hydrogen bonding). In this case, modifications in the suspension’s pH will result in: alterations in surface charge characteristics of hematite since H+ and OH− are the potential determining ions; and, changes in the ionic nature of the polyacrylamides due to hydrolysis, especially under basic pH conditions. A brief discussion of the above two factors is presented below.

Surface Chemical Properties of Hematite

The isoelectric point (iep) of synthetic Fe2O3 (hematite) used in this study was determined by electrophoretic measurements using a zeta meter to be pH 8.1. The iep and pzc (point of zero charge) values for hydrated iron oxide precipitates by slow and fast acid-base titration methods have been reported to be in the pH range of 8.5 to 9.3 (Parks and deBruyn, 1962; Onoda and deBruyn, 1966; and Atkinson, Posner, and Quirk, 1967). Differences in the iep value obtained in this study and those reported elsewhere can be due to the materials used, or, it could be due to techniques employed for determining the iep and pzc values. A detailed discussion of electrochemical properties of the oxide solution interface is presented by Ahmed (1975).
investigation on the nature of association of cobalt in different mineral phases, particularly in olivine and plagioclase, become of interest.

Table 5—Distribution of Nickel, Cobalt, and Sulfur in Bulk Sulfide Flotation Tailings

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Nickel (w%)</th>
<th>Nickel (w%)</th>
<th>Cobalt (w%)</th>
<th>Sulfur (w%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>47.0</td>
<td>16.0</td>
<td>11.5</td>
<td>0.06</td>
</tr>
<tr>
<td>Olivine</td>
<td>25.0</td>
<td>18.8</td>
<td>2.8</td>
<td>0.066</td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>15.6</td>
<td>7.0</td>
<td>0.025</td>
<td>0.007</td>
</tr>
<tr>
<td>Biotite</td>
<td>4.2</td>
<td>6.7</td>
<td>5.5</td>
<td>0.06</td>
</tr>
<tr>
<td>Magnetite</td>
<td>2.5</td>
<td>3.3</td>
<td>2.0</td>
<td>0.90</td>
</tr>
<tr>
<td>Ilmenite</td>
<td>4.2</td>
<td>3.7</td>
<td>0.020</td>
<td>3.1</td>
</tr>
<tr>
<td>Sulfides</td>
<td>0.3</td>
<td>0.7</td>
<td>0.015</td>
<td>68.9</td>
</tr>
<tr>
<td>Composite</td>
<td>100.0</td>
<td>100.0</td>
<td>0.020</td>
<td>100.0</td>
</tr>
<tr>
<td>Head ash</td>
<td>0.060</td>
<td>0.014</td>
<td>0.025</td>
<td>0.22</td>
</tr>
</tbody>
</table>

*Estimated from the chemical composition of sulfide flotation concentrate (Figure 3).

Summary

Laboratory concentration tests were run to study the possibility of recovering byproduct minerals from flotation tailings of copper-nickel bearing Duluth gabbro. A flowsheet involving gravity concentration, followed by low-intensity magnetic separation, sulfide flotation, and electrical concentration of the gravity concentrates for the separation of magnetite, residual sulfides, ilmenite, and olivine was developed. It also included high-gradient magnetic separation and biotite flotation of the gravity tailings for the separation of plagioclase and biotite. The flowsheet was tested on six Duluth gabbro samples taken at five different locations of the mineralized area. The flowsheet was shown to be relatively insensitive to the regional characteristics of the ore. The use of a Humphrey spiral in preconcentrating the heavy minerals ahead of a shaking table showed considerable promise in lightening the load to the shaking table and also to the high-gradient magnetic separator for the concentration of plagioclase.

Only the ilmenite concentrates met commercial specifications. Magnetite, plagioclase, biotite, and olivine were either too low in grade, or marginal. Attempts were made to further upgrade these mineral fractions and the limit of purity of each byproduct was ascertainment. However, byproducts recovered in the above flowsheet were rather small, altogether amounting to 15 to 45% by weight. It becomes of interest to ascertain the effect of closing the circuits on the recovery and on the purity of each byproduct.

Acknowledgment

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Koenig, C.W., 1980, Ohio State University, personal communication.


Minnesota Environmental Quality Board, 1979, The Minnesota Regional Copper-Nickel Study, five volumes.


Solution Chemistry of Polyacrylamides

Hydrolysis of polyacrylamide type polymers containing amide (-CONH₂) groups has been reported to occur under both acidic and basic pH conditions (Huguchi and Senju, 1972; Moens and Smets, 1957; Pinner, 1953; and Smets and Heibain, 1959). Since hydrolysis of amide groups by acids has been reported to be significant only at temperatures higher than 100°C (212°F), it can be assumed that under experimental conditions of 25°C (77°F) polymer structure did not change in the acidic pH range. Kinetics of hydrolysis of polyacrylamides under basic pH conditions are fast enough to result in conversion of a significant number of -CONH₂ groups to -COOH groups in the following manner (Kulicke and Klein, 1978):

\[
RCONH₂ + OH⁻ \rightarrow RCOOH + NH₃
\]

Thus, depending on the pH that governs the dissociation of -COOH groups, there could be changes in the ionic nature of the polyacrylamide type polymers. For example, upon hydrolysis, a nonionic polyacrylamide (PAM) can behave as an anionic polymer, whereas there can be an increase in the anionic nature of a sulfonated polyacrylamide (PAMS). Changes in the ionic nature of a cationic polyacrylamide (PAMD) as a function of pH are more complex. The overall charge of PAMD is based on the hydrolysis of the -CONH₂ groups to -COOH groups and, hydrolysis of the amine group (from DMAPMA-the comonomer) attached to the polymer backbone to neutral RNH₂ groups. At higher pH values, therefore, positive charge density of the cationic polyacrylamide will be reduced.

Experimental

Materials

Hematite — synthetic hematite, (99.2-99.5% Fe₂O₃) was obtained from Pfizer, Inc., and its particle size was reported to be 99% less than 5 μm (2500 mesh). Surface area of the sample using nitrogen as the adsorbate was determined by the Quantasorb to be 8.7 m²/g (3.3 cu ft per oz).

Polymers — C¹⁴ tagged nonionic and ionic polyacrylamides were synthesized using radiation induced hetero- genous polymerization technique. The synthesis procedure was similar to that recommended by Wada, Sekiya, and Machi, 1975, 1976). An overall monomeric concentration of 2.5 kmol/m³ was maintained in an acetone (45%)–water (55%) solvent at pH = 7.5. Polymerization was achieved using a Co¹⁶ source at a dose rate of about 1 k Rad/h. Additional details of the synthesis and characterization techniques have been given elsewhere (Moudgil, 1981).

Anionic copolymers (PAMS) were synthesized using 2-acrylamido-2-methyl propane sulfonic acid (AMPS) a product of Lubrizol Corp as the comonomer.

Cationic polyacrylamides (PAMD) were synthesized using dimethyl-amino propyl methacrylamide (DMAPMA) as the comonomer. This reagent was received in the stabilized form from the Jefferson Chemical Co. The hydroquinone inhibitor was removed by passing a 50:50 aqueous solution of this reagent through an activated carbon column. The aqueous solution obtained was used immediately after the inhibitor removal stage.

Viscosity average molecular weight of the polymers was estimated using the Mark-Houwink relation \[\eta = KM^a\], where [\eta] is the intrinsic viscosity, \(K\) is the average molecular weight, and 'K' and 'a' are constants for a given polymer solvent system (Huggins, 1958). For polyacrylamide solution in water, values of 'K' and 'a' are given as 6.31 × 10⁸ and 0.8, respectively (Polymer Handbook, 1974). These constants are reported to be valid for polymers of up to 500,000 molecular weight. Values of 'K' and 'a' for higher molecular weight polyacrylamides are not available. Therefore, the above values were used to estimate average molecular weights in the range of one million or more. The Mark-Houwink relation was used to estimate molecular weights of polyacrylamides with sulfonate and amine functional groups also, because no other relationships for polyelectrolytes of this type are reported. Since the amount of comonomer in the polyelectrolytes is small (5 mol %), it might be expected that the [\eta] versus M relationship will be governed by the behavior of the backbone (polyacrylamide). This will be even more true if the contribution of the ionic functional groups towards the extension of the polymer molecule was suppressed. This was achieved by measuring the intrinsic viscosity of the ionic polymers under high ionic strength conditions. Viscosity average molecular weights of the polymers were determined to be 2.5 million for nonionic polyacrylamide (PAM), 2.1 million for anionic polyacrylamide with sulfonate functional group (PAMS), and 1.9 million for cationic polyacrylamide with amine functional group (PAMD).

Inorganic reagents — Fisher certified NaOH and HCl were used for pH modification. ACS reagent grade NaCl, a product of Amend Drug and Chemical Co., was used for adjusting the ionic strength.

Water — Triple distilled water (TDW) of specific conductivity of 10⁻⁹ mho was used in this investigation.

Techniques

Adsorption tests — 0.4 g (0.0014 oz) of material was equilibrated with 8 cm³ (0.5 cu in.) of 3 × 10⁻² kmol/m³ NaCl solution in a screw cap glass vial for four hours by shaking at the desired temperature in a wrist action shaker. After four hours of equilibration, pH was adjusted using NaOH or HCl and the suspension was further equilibrated for two hours. Required amount of polymer solution was then added and the suspension was agitated for an additional 12 hours before adding the surfactant solution. After adding the surfactant, two more hours of agitation was required to reach the equilibrium. After equilibration, pH of the suspension was measured using a thin glass electrode attached to a digital Corning pH meter (Model 125). The contents of the vial were transferred to a centrifuge tube and were centrifuged in a IEC Model B20-A centrifuge at 15,000 rpm for 10 minutes. Residual amount of the polymer and the sulfonate were determined in the supernatant and adsorption densities were calculated using the respective calibration curves.

Reproducibility of the adsorption measurements at lower residual polymer concentrations (< 1000 mg/kg, or 0.07 oz per lb) was found to be within 4%. Accuracy of measurements generally was better in the lower polymer concentration range.

Analytical — the amount of C¹⁴ labeled polymers was determined using a Beckman Model LS 100C spectrophotometer.
Results and Discussion

Preliminary studies were conducted to evaluate the effect of parameters such as agitation intensity and time, which formulate the equilibrium adsorption test procedures. Also, the reversibility of adsorption of the polyacrylamide type polymers on hematite was investigated since knowing the extent and rate of desorption helps in understanding the mechanism of the polymer adsorption process.

Effect of Agitation on Polymer Adsorption Properties

To determine if shaking the polymer solution during equilibrium adsorption tests modifies its adsorption behavior in any way, non-equilibrium adsorption tests involving one hour of agitation were conducted. One of the polymer solutions used in the adsorption test was shaken in a wrist action shaker for 12 hours (duration of the equilibrium adsorption tests) and the other was kept on a bench top. Adsorption results obtained after one hour of agitation are presented in Table 1. Also, to determine if the two agitation conditions had resulted in any substantial changes in the molecular weight distribution of the polymers, intrinsic viscosity of the supernatant was measured using a capillary viscometer. The estimated molecular weights are also presented in Table 1. Experimental data indicates that agitation during the adsorption tests did not cause changes in the structure of the polymer molecules to affect their adsorption behavior on hematite.

Chromatographic Separation of Polymer During Adsorption

It has been reported that displacement of initially adsorbed low molecular weight fraction by higher molecular weight fraction could occur if the molecular weight distribution of the polymer is broad (Felster, Moyer, and Ray, 1969; Kothoff and Gutmacher, 1952). To determine if there was any preferential adsorption of higher molecular weight fractions during the present investigation, molecular weight of the polymer before and after the equilibrium adsorption test was estimated. Table 2 results show that molecular weight estimates of the polymer before and after completion of an adsorption test were within ±10%, the accuracy limit of the intrinsic viscosity technique used for molecular weight estimation. This indicated that either the molecular weight distribution of the polyacrylamide used was not broad enough to result in any measurable chromatographic separation during the adsorption process, or that the present system was not capable of causing any such separation.

Desorption-Reversibility of Polymer Adsorption

It is possible to obtain some knowledge of the strength of the bond formed between the polymer species and the adsorbent by determining the extent of desorption or the reversibility of the polymer adsorption process. The type of solvent has been known to affect the rate and amount of desorbed polymer to a considerable extent. Desorption normally is slow and incomplete when the polymer is adsorbed from dilute solutions, whereas, from concentrated solutions, it is rapid and frequently complete (Lipatov and Sergeeva, 1971). This could be the result of differences in the stability of the adsorbed polymer from dilute and concentrated solutions. In the former case, optimum number of bond formations can occur between the polymer molecules and the adsorbent. However, in the case of adsorption from concentrated solutions, less than optimum number of bond formations are possible due to “crowding in” by other polymer molecules on the adsorbent surface.

An attempt was made in this investigation to desorb the polymer from the hematite surface by decreasing the bulk concentration (by replacing part of the solution above settled solids with salt solution or TDW) and shaking the suspension in a wrist action shaker for an additional 12 hours. It was expected that desorption of the adsorbed polymer molecules would increase the “new” residual polymer concentration. A decrease in the residual concentration, on the other hand, would indicate continued adsorption. Table 3 results make it clear that desorption of the polymers upon dilution, irrespective of their ionic nature, did not occur under these experimental conditions.

Table 2 — Chromatographic Separation of Nonionic Polyacrylamide (PAM) During Adsorption on Hematite

<table>
<thead>
<tr>
<th>NaCl Conc.</th>
<th>3 x 10⁻² kmol/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Polymer</th>
<th>pH</th>
<th>Residual Polymer Conc. after 12 Hrs. of Adsorption mg/kg</th>
<th>Residual Polymer Conc. after 12 Hrs. of Desorption mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAM</td>
<td>4.27</td>
<td>671</td>
<td>251</td>
</tr>
<tr>
<td>PAM</td>
<td>6.86</td>
<td>723</td>
<td>271</td>
</tr>
<tr>
<td>PAM</td>
<td>5.90</td>
<td>718</td>
<td>289</td>
</tr>
<tr>
<td>PAM</td>
<td>3.72</td>
<td>470</td>
<td>176</td>
</tr>
<tr>
<td>PAM</td>
<td>6.86</td>
<td>622</td>
<td>233</td>
</tr>
<tr>
<td>PAM</td>
<td>6.53</td>
<td>635</td>
<td>238</td>
</tr>
<tr>
<td>PAM</td>
<td>6.78</td>
<td>662</td>
<td>268</td>
</tr>
<tr>
<td>PAM</td>
<td>6.78</td>
<td>707</td>
<td>286</td>
</tr>
</tbody>
</table>
during the dilution process to assess the desorption, the surface to volume ratio (S/V) is decreased. That can have a major influence on the polymer adsorption. Consequently, this might lead to the erroneous conclusion that the polymer is irreversibly adsorbed. In the present study, however, S/V ratio was maintained constant because a given volume of the supernatant after adsorption was replaced with an equal amount of the liquid without any polymeric species present in it. Also, in the case of polydisperse polymers under equilibrium conditions, it was reported that the "higher" molecular weight fractions are preferentially adsorbed and the residual polymer in the bulk solution should essentially consist of "lower" molecular weight fractions. Once again, estimating the molecular weight of the residual polymeric species in the present study, using the intrinsic viscosity measurements, did not reveal any significant difference in the molecular weights calculated before or after the adsorption tests. In other words, no chromatographic separation of the polymeric species was observed. It should be noted that there are no reports that prove the reversibility of adsorption, even in the case of monodisperse polymeric systems using a solvent of similar thermodynamic character.

Adsorption of Polymers on Hematite

**pH Effect:** Adsorption of acrylamide based homo- and copolymers on hematite under different pH conditions is presented in Figs. 1 to 5. Most of the adsorption isotherms are characterized by a higher slope at low concentrations followed by a slower uptake of the polymer at higher concentrations. A plateau, however, is not reached within the polymer concentration range tested. It was determined also that, up to a certain initial polymer concentration, almost all of the polymer was adsorbed on the solid, and it was only at higher concentrations that a partitioning of the polymer between the surface and the bulk solution was detected. This type of adsorption behavior is characteristic of monolayer type of adsorption for nonpolymeric material and can be described by the Langmuir equation. In the case of polymer adsorption, however, any fit of the data to the Langmuir equation is probably fortuitous since polymer molecules can assume different conformations and exhibit varying degree of attachment to the surface as adsorption progresses. Moreover, adsorption of polyacrylamides used in the present study was found to be irreversible upon dilution, and lateral interactions between adsorbed polymer molecules cannot be ruled out. Thus, two of the basic assumptions involved in the derivation of the Langmuir equation are violated. Although adsorption isotherms generated in the present study were similar in shape to the Langmuir isotherm, they did not satisfy the criterion of a linear C/A versus C relation.

One common feature of the adsorption of polyacrylamide type polymers on hematite is that adsorption is lower under basic pH conditions than at acidic or neutral pH (Fig. 1 to 3). This can be attributed to the polymer hydrolysis above pH 8 resulting in the formation of carboxylic acid functional groups in all three types of polymers. For example, at pH 11.5, hematite is negatively charged and introduction of any negative charges on the polymer backbone will result in an increase in the electrostatic repulsion, thus reducing the polymer adsorption.

Adsorption of nonionic polyacrylamide (PAM) was found to increase with decreasing pH (Fig. 1). This is in accordance with the mechanism proposed earlier that adsorption of polyacrylamides on hematite occurs by hydrogen bonding of the amide groups to the hydrogen donating surface sites, which will increase with a decrease in pH (Linke and Booth, 1959; Gebhardt and Fuerstenau, 1982). At pH values higher than 8.1, not only the hematite surface is negatively charged, but the polymer itself will be anionic in nature. Electrostatic charge repulsion at such pH values, therefore, will become significant, resulting in reduced adsorption.

In the case of anionic polyacrylamide with a sulfonate functional group (PAMS), its adsorption behavior on hematite as a function of pH is similar to PAM (Fig. 2). Anionicity of the polymer at pH above 8.1 and therefore, electrostatic charge repulsion, will be even more significant in this case.

Adsorption of the cationic polyacrylamide (PAMD) on hematite at three pH levels is plotted in Fig. 3. At pH 2.7 and 7.2, hematite will exhibit a net positive charge, the charge density being higher at the lower pH value. However, at both these pH levels, the polymer charge characteristics will remain unchanged. Therefore, because of the electrostatic repulsion, polymer adsorption on hematite by hydrogen bonding will decrease. The reduction in the polymer adsorption will be more pronounced at pH 2.7 than at pH 7.2.
Adsorption of nonionic polyacrylamide (PAM) on hematite at 25°, 45°, and 75°C (77°, 115°, and 167°F) is plotted in Fig. 6. Similar adsorption behavior was observed at 25°C and 45°C (77° and 115°F). However, at 75°C (167°F), a trend towards higher adsorption was obtained. Such behavior is indicative of significant influence of the entropic effects on the adsorption of process.

At pH 10.9, hydrolysis of the cationic polyacrylamide will induce negative charges (RCOO⁻) on the polymer backbone. This results in electrostatic repulsion between similarly charged polymer and hematite particles. The negative charge repulsion at pH 10.9 can be expected to be more significant than the positive charge repulsion at pH 2.7 and 7.2, since the amount of cationic amine functional groups (3 mol %) is less than the amide groups in the polymer, which will hydrolyze to RCOO⁻. It is therefore expected that the polymer adsorption will be lower at pH 10.9 than at the two lower pH levels (Fig. 3).

Ionic Strength Effect: Ionic strength changes can affect polymer adsorption through modifying the solvent power of the medium, and increased competition between counterions and polymer segments for adsorption at the solid/liquid interface. If the polymer is more soluble at higher ionic strength, a decrease in adsorption would be expected. The increased competition between added ionic species and polymer molecules would also lead to reduced adsorption. A third factor to be considered for polyelectrolytes is the possible modifications in polymer conformation as a result of the added indifferent electrolyte (Muller, Laine, and Fenyo, 1979). Electrostatic repulsion between charged functional groups will be minimal in the presence of salt, permitting increased coiling of the polymer chain. This should lead to a reduction in area per molecule, and, thus, an increase in adsorption.

Adsorption of PAM (nonionic polyacrylamide) on hematite at different concentrations of NaCl is plotted in Fig. 4. There is no significant effect of varying the salt concentration from 0 to 5.1 kmol/m³ NaCl on the adsorption of PAM on hematite. These results indicate that there are no charged sites (due to hydrolysis) associated with the polymer backbone. Considering that adsorption of polyacrylamide on oxide minerals is by hydrogen bonding, no significant effect of ionic strength is expected. Adsorption of PAMS (anionic polyacrylamide-a polyelectrolyte) on hematite (Fig. 5) was determined to be higher at higher salt concentration. This suggests that changes in polymer conformation might influence the adsorption of PAMS more than the increased competition between the counterions.

Temperature Effect: Variations in temperature can affect polymer adsorption through changes in solvent power of the medium, and adsorption of the solvent molecules competing with the polymer. Both factors have similar roles in monofunctional solute adsorption, except that for polymers, entropic effects due to adsorption of the solvent molecules competing with the polymer can be considerable.
Conclusions

Based on the above discussion, the following conclusions regarding the adsorption of polyacrylamide type polymers on hematite are reached.

Adsorption of the ionic and nonionic polyacrylamides on hematite is governed primarily by hydrogen bonding between the surface oxygen and the oxygen or nitrogen on the polymer. Electrostatic interactions between the polymer functional groups and the hematite surface play only a secondary role in the present system because of the relatively low degree of functionality of the copolymers.

The relatively small effect of salt addition on the adsorption of anionic polyacrylamide (PAMS) on hematite and the negligible effect of ionic strength on the adsorption of nonionic polyacrylamide (PAM) on hematite indicates that either the changes in parameters such as solvent power of the medium and conformation of the polymer are not significant, or, their effects are mutually cancelled out.

The effect of temperature on the adsorption of polyacrylamide on hematite was not found to be significant, leading to the conclusion that entropic, rather than enthalpic changes, play a major role in the adsorption process.

Desorption tests indicated that, irrespective of the polymer charge, polymer adsorption on hematite upon dilution can be considered to be irreversible under present experimental conditions.

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References


TECHNICAL NOTE

Nuclear Instrumentation in Coal Preparation Plants

C.H. Baab and L.S. Kolbert

Introduction

In June 1981, the Electric Power Research Institute (EPRI) issued a report titled “Control Systems in Coal Preparation Plants” to determine the status of instrumentation and automation systems in the coal preparation industry. EPRI concluded that the control systems presently being employed in the US coal preparation plants “are relatively primitive compared with those in other mineral processing industries; and analytical instrumentation is virtually non-existent.”

With tighter specifications on the quality of steam coal, interest is increasing in more sophisticated control systems. One type of device that is currently assisting the preparation plant operator optimize and control the coal cleaning process is nuclear based instrumentation. Nuclear instrumentation includes methods for measuring weight, level, and density as well as for performing elemental analysis on coal.

Major Features and Benefits of Nuclear Measurement and Analysis Systems

There are many features and benefits of nuclear instrumentation. The major benefit is that nuclear instrumentation is non-contacting. The measuring heads do not contact the process materials. This enables measurements of corrosive, abrasive, or high temperature materials with no loss of performance, reliability, or useful life. Also, there are no moving parts to wear or be fouled by dust or corrosion.

Installation is simple and inexpensive. For instance, density gauges are simply clamped onto existing pipe runs. Weigh scales and level switches usually require nothing more than welding brackets to customers’ equipment. Once installed, routine maintenance can be performed without interrupting the process. Thus, nuclear instrumentation is highly reliable and easily installed and maintained. The operating life of the instrumentation is virtually unlimited.

Principle of Operation

Nuclear belt weigh scales, point level switches and density gauges all operate on the gamma-ray transmission principle. A beam of gamma radiation from a radioisotopic source is projected through the process material either on a belt, in a vessel, or in a pipe. Opposite the source is a radiation detector whose electrical output is proportional to the intensity of the radiation it absorbs.

Gamma radiation is part of the same electromagnetic spectrum that encompasses light, infrared, and x-rays. In many respects, gamma radiation behaves much like light. However, it is far more penetrating and can be transmitted through considerable thickness of materials that are opaque to visible light, e.g., several inches of steel.

Types of Nuclear Instrumentation in Coal Preparation Plants

There are four types of nuclear instrumentation presently being employed in coal preparation plants. They are:
- Belt Weigh Scales
- Point Level Switches
- Density Gauges
- Coal Analysis Equipment

Each type of instrumentation has a number of potential applications within the plant. What follows is a discussion of three different types of devices and their applications.

Weigh Scales

In coal preparation plants, weighing instruments are used for measuring material throughput, totalized weight, and batch weight on conveyor belts and other transport equipment. They are also used on drag chain conveyors, vibrating conveyors, and screw conveyors. Weighing is important for receiving the run-of-mine coal, controlling mass flow, scheduling production, and loading and shipping the washed coal to market.

There are two basic types of weighing instruments: gravimetric and nongravimetric devices. Gravimetric devices are units which measure the pull of gravity on the material being weighed. Nongravimetric devices are not dependent on the force of gravity on the sample. Nuclear weigh scales are the most prevalent nongravimetric devices used.

The nuclear weigh scale works on the same basic principle as other nuclear gauges. The greater the quantity of material placed in the path of a radiation beam, the more radiation will be absorbed by the material. In weigh scales, Cesium 137 source is generally placed above the moving stream of material so that the radiation is directed through the material. An ion chamber radiation detector is on the opposite side of the material. The radiation passing to the detector generates a signal which is inversely proportional to the weight of the material present. This signal is amplified and integrated with the speed of the process flow yielding the weight. The weight is indicated and can be totalized for throughput, batch control, etc.

In conclusion, radiation weighing methods have become well established in the coal preparation industry throughout the world. As mentioned before, this device finds its most