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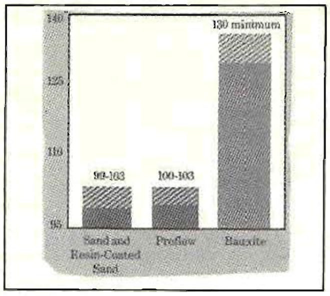
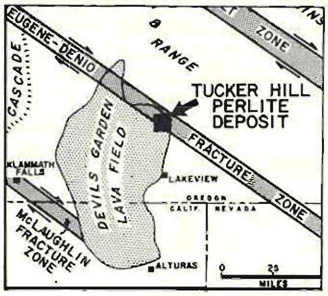
Page 1281



Page 1287



Page 1301

Page 1324

DEPARTMENTS

COVER

Saint Barbara's feast day is celebrated on Dec. 4. So it seems appropriate we review the legend and history of this patron saint of mining. Feature begins on page **1281**. (Cover drawing by Pan Eimon.)

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FEATURE ARTICLES

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Design of permanent block stopping to resist strata convergence

R.E. Ray, Jr., J.W. Stevenson, J.A. Berry, and R.J. Timko

Abstract – *Conventional concrete block plastered with a cementitious coating is the most common material used in the construction of permanent stoppings to direct airflow in underground mines in the US. All mines experience various degrees of strata convergence depending on depth of overburden, geological conditions, and type of roof support employed. Strata convergence will cause cracks and joint openings in masonry stoppings, resulting in significant air leakage losses. Where strata convergence is severe, complete structural failure of the stopping can ultimately occur. Reconstruction of damaged or destroyed stoppings adds expensive overhead to mining operations, and even greater expenses are incurred from the additional fan horsepower required to overcome leakage losses.*

Ideally, a stopping should maintain high resistance to airflow while yielding to strata convergence. By properly incorporating a polyisocyanurate rigid foam material within the masonry block structure, stopping service life can be increased in mines experiencing strata convergence problems such as floor heave, roof loading, and lateral rib movement.

Introduction

One of the prime problems and concerns caused by convergence of the roof, ribs, and floor in underground mines is damage to ventilation control stoppings. Fractured or crushed-out stoppings and overcasts permit airflow to short circuit from intakes to returns. According to Kingery (1960), as little as 30% of the total quantity of air ventilating many underground mines reaches the last open crosscut. To provide a sufficient quantity of air at the working face for dilution of methane gas and float coal dust, additional fan horsepower must be supplied to compensate for air leakage through damaged or destroyed ventilation controls. Increased fan horsepower and the repair or reconstruction of ventilation controls obviously produce higher ventilation operating costs. Clearly, any stopping design concept that extends service life and reduces leakage will result in greater ventilation efficiency and lower operating costs.

Masonry stopping design

Stoppings are usually constructed of solid or hollow core masonry blocks. Two construction techniques are used: wet wall, where cement mortar is applied to all joints; and dry stack, where no mortar is used. To reduce air leakage through masonry stopping walls, the stopping faces are often coated with a cementitious sealant. As reported by Timko (1982), the sealant is usually enhanced with glass fibers and various additives to increase strength and adhesion. These are typically applied with a brush or trowel.

In mines with little or no convergence, a masonry block stopping may exist for years before maintenance becomes necessary. Air leakage first becomes evident around the stopping perimeter, especially the roof. It appears that the wood wedges, used to secure the stopping to the roof, dry and shrink, causing a fairly low resistance path for air to flow. In addition, as the pressure differential increases across the stopping, any degradation in the roof or ribs will gradually permit air leakage. The same problem can occur beneath the stopping. However, a properly constructed footing built beneath the stopping greatly reduces the potential for leakage.

Whenever convergence exists, masonry block stopping life is greatly reduced. A stopping may be damaged by roof, rib, or floor movement. The first indication that the stopping is under compression occurs when the mortar face sealant and possibly even the faces of the masonry block begin spalling from the stopping perimeter. This is followed by joint fracturing and destruction of masonry blocks near the area of maximum convergence. Once the blocks begin to crush under compressive load, the stopping has lost its integrity and can no longer be considered substantial by US Mine Safety and Health Administration (MSHA) standards. This can occur over months or may take place in a matter of days.

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Compressible media in masonry block stoppings

As mines progress deeper, the large amount of overburden makes convergence a chronic problem. To ensure extended airtightness, stoppings should have the ability to compress with their perimeters. Many mines are evaluating the economics of various types of compressible media, or squeeze blocks.

A rigid polyisocyanurate foam has been developed for use as a squeeze block in underground mine stoppings. This material has been accepted by MSHA for use as a perimeter seal and load absorbing medium in permanent stoppings. It is produced in boards 102 mm (4 in.) thick by 1220 mm (48 in.) long in 203 mm (8 in.), 305 mm (12 in.), and 406 mm (16 in.) widths. The density of the foam is less than 40 kg/m^3 (1.5 lb per cu ft). Jim Walter Resources Inc., Mining Division, and several other mining companies have conducted extensive tests evaluating the performance of the foam boards in stoppings constructed in areas experiencing strata convergence problems.

Jim Walter Resources (JWR) operates six underground coal mines in central Alabama. Two Jim Walter mines, Bessie and Nebo, are located north of Birmingham and lie beneath relatively shallow cover. The remaining four mines — Blue Creek No. 3, No. 4, No. 5, and No. 7 — are located west of Birmingham in Jefferson and Tuscaloosa counties. They lie beneath 396 m (1300 ft) to 701 m (2300 ft) of cover. Mines No. 3, 4, 5, and 7 all operate in the Blue Creek coal bed, although No. 4 also mines the Mary Lee coal bed, which lies several feet above the Blue Creek.

Design of squeeze stoppings for floor heave conditions

The Mining Division of Jim Walter Resources Inc., with cooperation from Jim Walter Research Corp. (JWRC), began experimenting with the rigid foam boards in April 1982 after severe floor heave conditions at Blue Creek No. 5 Mine, the deepest vertical shaft coal mine in the US (701 m, or 2300 ft), had destroyed more than 100 conventional solid masonry block stoppings on two development sections in the southwest portion of the mine. A map of the area is given in Fig. 1. An expanded zone of the Blue Creek coal seam containing thin, intermittent layers of coal, shale, and a soft, almost pliable fire clay characterize this portion of the mine. Since mining the entire seam would have resulted in a low clean coal recovery and excessive mining heights (4.6 m, or 15 ft), a bench was established on top of a competent layer of shale. The bearing strength of the underlying laminae was insufficient to support the stress transferred by the 30.5 × 30.5 m (100 × 100 ft) pillars and severe floor heave conditions developed. Because of the extreme thickness of the weak floor layer, many rebuilt masonry block stoppings were also crushed out as heave conditions worsened (Fig. 2).

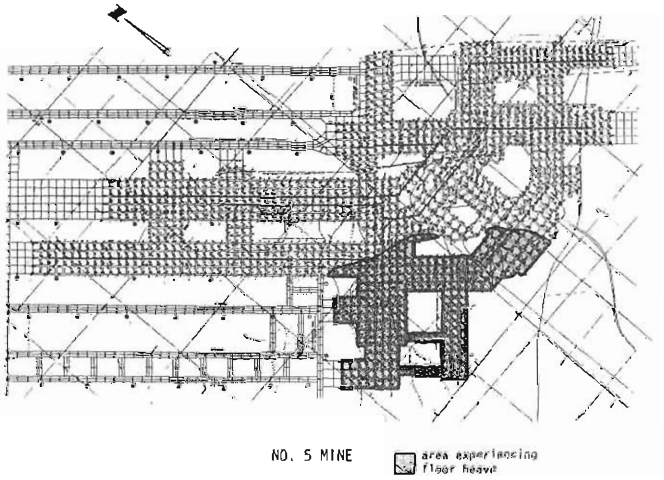

Fig. 1 — Map of Blue Creek No. 5 Mine showing extent of floor heave

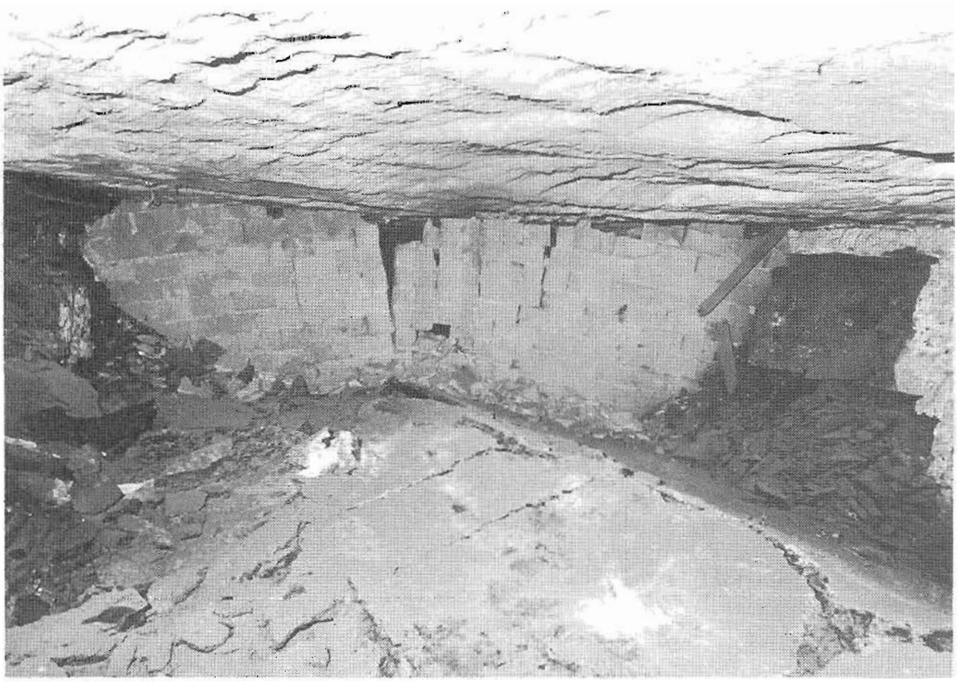

Fig. 2 — Stopping destroyed by floor heave, Blue Creek No. 5 Mine

The first efforts to protect stoppings from floor heave at No. 5 Mine used wooden 102 × 102 mm (4 × 4 in.) cross-collars laid longitudinally beneath the first row of blocks and between the top row of blocks and the roof. The cross-collars provided little or no protection for the solid block structure, and the rigid foam material was then substituted as the compressible medium in the stopping. One to three courses of foam boards laid longitudinally on a clear floor footing serving as a knee wall to receive subsequent courses of masonry blocks, and one or two courses of foam boards installed between the top of the stopping and the roof to absorb or cushion the effect of roof loading increased stopping service life by as much as 400%.

To counter the severity of the heave experienced at No. 5 Mine (approaching entry closure in some cases), JWR experimented with placing additional courses of foam boards across the base of the stoppings to provide extra relief against the induced parabolic stress that forces the stoppings into arching or ruptured configurations. However, these experiments demonstrated that using more than three layers of rigid foam (305 mm, or 12 in.) to build the stopping base created stability problems during construction and caused the block wall to lean severely and sometimes topple. In fact, mines with working heights exceeding that of No. 5 (1.8 to 2.4 m, or 6 to 8 ft) may require reduction of the maximum recommended base thickness of rigid foam of 305 mm (12 in.). To maintain structural stability, while still providing additional courses of rigid foam for relief from severe floor heaving, a design using a 76 × 305 mm (3 × 12 in.) by 5.5 m (18 ft) long bridge-plank, or board, placed across the top of the base section of foam was developed. In this design, the bridge-plank is supported at both ends by 406 × 406 mm (16 × 16 in.) concrete block columns and serves as a level foundation for subsequent courses of blocks (Fig. 3).

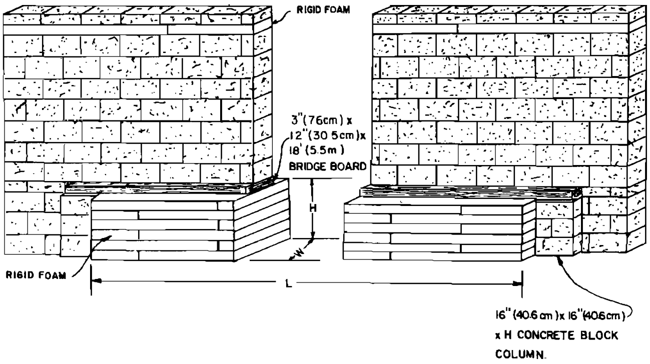

Fig. 3 — "Bridge-board" stopping

Although the stopping design shown in Fig. 3 allows the builder to increase the height of the rigid foam zone serving as the base of the stopping, the tendency for the foam to act as a column under compression and buckle (or "kick out") becomes more pronounced with increased height. Thus, a compromise must be reached between the greater stability of a shorter column and the need to provide a sufficient amount of material to deform under the influence of the heave. JWC is continuing efforts to improve the effectiveness of the combination rigid foam and concrete block stopping by designing for a base of increased height (610 to 910 mm, or 24 to 36 in.), while attempting to reduce its bending tendencies. Widening the column width "W" of the rigid foam base (Fig. 3) is one method being evaluated to alleviate "kicking out" tendencies.

Design of squeeze stoppings in longwall panels

Based on the success of the rigid polyisocyanurate foam in extending service life of stoppings at No. 5 Mine, its use has been expanded to JWR's Blue Creek No. 4 Mine. This mine is experiencing severe floor heave and rib convergence conditions in longwall headgate and tailgate entries. The Blue Creek coal seam and the overlying Mary Lee seam are both mined at No. 4, as well as the layer of "middleman" shale rock separating the two seams. Side abutment pressures from the first longwall panel extracted at No. 4 Mine have produced severe lateral rib convergence and floor heave in each of the four entries of the tailgate and headgate panels, and numerous stoppings have been damaged or destroyed.

A homotropal system of longwall ventilation (intake air flows in the same direction as the cutting cycle — tailgate to headgate) is employed at No. 4 Mine, with the longwall tailgate entry used as an intake air course. The intake air directed through the headgate entries joins the face air (originating from the tailgate end) at the stage loader and provides additional methane dilution capacity. The homotropal ventilation system requires a separation between the intake air in the tailgate entry of the active longwall and the gob from worked out longwall panels being ventilated by return air. Thus, maintaining the integrity of the stopping line between the tailgate entry and the gob is critical to the success of the ventilation system.

Rib convergence in the longwall panels of No. 4 Mine manifests itself in the form of lateral and inverted parabolic stress on the stopping, which appears to initially crush the top corner or shoulder area of the masonry stopping. Rib convergence damage may be alleviated by installing additional rigid foam in the shoulder area of the stopping. The stopping illustrated in Fig. 4 is designed to prevent rib convergence damage and to withstand the 305 to 610 mm (12 to 24 in.) of floor heave which is expected in the tailgate entry of future longwall panels. By building these stoppings between the future tailgate entry and the future return entries of four-entry longwall panels during development, JWR hopes to eliminate, or at least substantially reduce stopping repair and rebuild costs when the longwall panel becomes active.

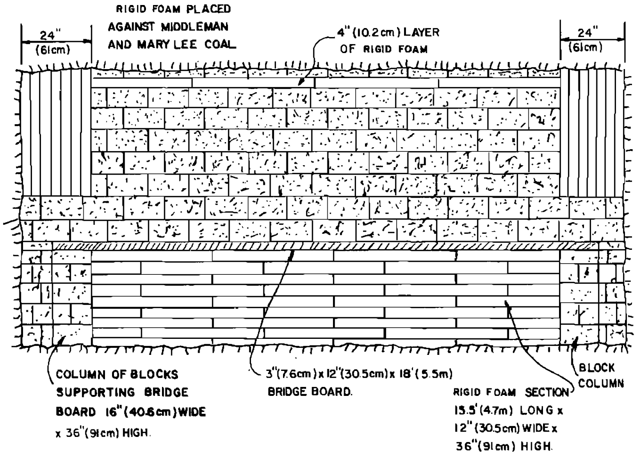

Fig. 4 — Design of foam board and concrete block stopping for rib convergence-floor heave conditions

Table 1 — Results of Stopping Leakage Tests Using SF_6 Technique

Number	Masonry Block Stopping	Compressible Stopping	Air Leakage $m^3/s-100m^{-2}/KPa$	Face Sealed	Convergence (m)	Comments
1		X	36.1 (1764 cfm/100 sq ft/in.w.g.)	No	0.46 (1.5 ft)	Mortar spalling from face
2		X	17.1 (834 cfm/100 sq ft/in.w.g.)	Yes	0.76 (2.5 ft)	Mortar spalling from face
3	X		29.3 (1430 cfm/100 sq ft/in.w.g.)	No	0.30 (1 ft)	Bottom center fractured
4		X	23.2 (1132 cfm/100 sq ft/in.w.g.)	Yes	0.61 (2 ft)	Mortar spalling from face
5		X	2.5 (123 cfm/100 sq ft/in.w.g.)	Yes	0.61 (2 ft)	Mortar spalling from face
6		X	7.4 (360 cfm/100 sq ft/in.w.g.)	Yes	0.30 (1 ft)	Mortar spalling from face
7	X		1.8 (89 cfm/100 sq ft/in.w.g.)	No	—	Small fractures along roof & floor
8	X		*	No	0.23 (.75 ft)	Face crushing out, numerous cracks

** Leakage exceeds SF_6 capability.*

Leakage performance of squeeze stoppings

Several rigid foam and concrete block stoppings at JWR's No. 5 Mine were evaluated for leakage performance using the sulfur hexafluoride (SF_6) tracer gas technique developed by the US Bureau of Mines. This procedure, demonstrated by Thimons (1974), involves erecting a temporary stopping from brattice cloth some distance from the stopping being evaluated, creating a known volume. A sampling time with several specific sampling intervals is then selected to measure the depletion of SF_6 with respect to time. Sample bottles are then analyzed on an electron capture gas chromatograph.

The actual leakage of the stopping being evaluated can be determined from the following equation:

$$Q = \frac{\ln (C_1/C_2)\,(-V)}{T_1 - T_2} \tag{1}$$

where:

Q = air quantity (cfm)
C_1 = SF_6 concentration (ppb) at time T_1 (min)
C_2 = SF_6 concentration (ppb) at time T_2 (min)
V = stopping to brattice curtain volume (ft^3)

However, due to varying parameters in underground mines (i.e., pressure differences, stopping sizes), the leakage value obtained cannot be directly compared to other stoppings in the mine.

To standardize all stoppings, two equations are used:

$$Q' = \frac{100Q}{A} \tag{2}$$

where:

Q' = air quantity (cfm) per 100 ft^2 stopping area
A = actual stopping area

$$Q'' = \frac{Q'}{p^n} \tag{3}$$

Q'' = air quantity (cfm) per 100 ft^2 stopping area per inch water gage pressure differential
p = pressure differential across stopping (in. water gage)
n = logarithmic change of leakage with pressure (typically, for block stoppings, $n = 0.9$)

Two types of stoppings were evaluated at No. 5 Mine - masonry block stoppings and the "bridge-board" type stopping shown in Fig. 3. Convergence had taken its toll on several stoppings. But, where little convergence had occurred, the masonry block stoppings remained substantial and relatively airtight.

Table 1 shows the results of the leakage tests conducted at No. 5 Mine. Eight stoppings were evaluated both visually and by the SF_6 technique. One can see that when convergence is minimal, typical masonry block stoppings are sufficient. However, as soon as perimetral loading begins, the masonry stopping performance declines rapidly. Conversely, when squeeze blocks are interbuilt with masonry blocks, the stopping remains intact much longer.

Two conclusions can be drawn from the stopping evaluations conducted at No. 5 Mine. First, compressible media interspaced in masonry block stoppings will retain structural integrity and airtightness longer than those stoppings built only from masonry blocks. Second, compressible stoppings with faces sealed will retain airtightness longer than stoppings lacking a face sealant.

Cost of rigid foam and concrete block stoppings

The increase in the initial cost of construction of a combination rigid foam and concrete block stopping at JWR ranges from about 8.5% (stopping design shown in Fig. 3) to about 25% (stopping design illustrated in Fig. 4). Table 2 provides a complete breakdown of the approximate labor and material costs of these stoppings.

Table 2 — Cost Comparison of Various Stopping Designs

Type of Stopping[1]	Material Cost	Labor Cost[2]	Total Cost
Concrete Block	$190	$576	$766
Rigid Foam-Concrete Block[3]	$255	$576	$831
Rigid Foam-Concrete Block[4] (similar to Fig. 4)	$380	$576	$956

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[1] *Stopping size of 2.6 m (8½ ft) × 6.7 m (22 ft) used in all calculations.*
[2] *Assuming 24 General Inside Laborer (GIL) man•hrs. required to deliver materials and build each stopping @ $24.00/man•hr. (includes fringes).*
[3] *305 mm (12 in.) of rigid foam across bottom of stopping, 102 mm (4 in.) across top.*
[4] *5 m (16 ft) long × 914 mm (36 in.) high × 305 mm (12 in.) wide section of rigid foam along bottom of stopping and 610 mm (24 in.) long × 1220 mm (48 in.) high × 305 mm (12 in.) wide section in each upper corner.*

Conclusion

In underground areas plagued by strata convergence problems, typical masonry block stoppings will retain structural integrity for only a short period of time. Stoppings that are able to compress with the surrounding strata are required for these areas. These stoppings are usually built of masonry block interspaced with a compressible medium, known as a squeeze block.

A rigid polyisocyanurate board has been used as a compressible medium in stopping construction in several of Jim Walter Resources' underground coal mines. By providing as much as a 400% increase in service life at an additional cost of only 8.5% to 25%, the combination rigid foam and concrete block stoppings can significantly reduce the increased ventilation costs associated with repairing or rebuilding stoppings damaged by strata convergence. ■

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Selective flocculation for the recovery of iron in Kudremukh tailings

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S.N. Mahapatra, and K.S. Narasimhan

Abstract – *Selective flocculation studies carried out with iron ore tailings generated at Kudremukh iron ore plant indicate that a concentrate containing 63% iron can be obtained from the tailings containing 34% iron with around 60% recovery. This opens up the possibility of recovering most of the iron lost in the tailings generated at 2 kt/h (2200 stph) while processing 22 Mt (24 million st) ore per year. This would mean that the productivity could increase by around 50%.*

In these studies, it has been established that caustic degraded tapioca starch is a most effective agent for selective flocculation. While potato starch after caustic degradation can also be used, neither the parent starch nor the amylopectin compound is as effective.

Introduction

While selective flocculation is one of the methods suggested for the beneficiation of fine grained, low grade ores, it has found commercial application in the utilization of very low grade iron ores (Anon, 1974). Although India is rich in iron ore reserves, a considerable amount of iron values are lost in the tailings of currently operating iron ore beneficiation plants. And it is desirable that most of these should be recovered from both the conservation and ecological points of view.

Characterization studies conducted thus far have revealed that in all cases of hematite ore treatment, it is possible to recover most of the iron minerals lost by classification followed by gravity methods applicable to fine particles (Reddy et al., 1983; Reddy et al., 1984). But the tailings generated at Kudremukh iron ore plant stands out as an exception to such a treatment (Reddy et al., 1983). At this plant (based on 600 Mt, or 661 million st, of weathered ore and 400 Mt, or 441 million st, of underlying primary low grade magnetite) processing 22.6 Mt (25 million st) of ore at a rate of 3.1 kt/h (3400 stph), 2.1 kt/h (2300 stph) of tailings containing 25.3% iron are produced (Reddy et al., 1983).

In view of the enormous amount of iron lost, which is essentially nonmagnetic, investigations were carried out to ascertain whether selective flocculation can be made applicable to recover the iron values lost as acceptable concentrates.

The majority of investigations in the area of selective flocculation are related to recovering iron oxides, both from natural ores and synthetic mixtures. And these efforts have culminated in the development of a commercial process adopted by the Cleveland Cliff Iron Ore Co. in its Tilden operation in the US (Anon, 1974).

In this plant, 10 Mt/a (11 million stpy) of nonmagnetic taconite ore containing 35.9% iron is ground mostly to below 25 μm (560 mesh). The iron oxide is selectively flocculated using starch while fine silica is dispersed using caustic soda and sodium silicate (Villar and Dawe, 1965). By this process, one-third of the silica is removed while the remaining coarser silica is removed by cationic flotation to obtain concentrates for pelletization.

In general, high molecular weight starch and starch derivatives, at instances with proper modification, have been used as flocculants for iron oxides. Certain polyacrylamide derivatives can also be used (Cooke, Schulz, and Lindross, 1952; Read, 1971). Starches, either direct or causticized, derived from potato, tapioca, and corn are found to be successful in selective flocculation of iron. It is considered that the amylopectin component of these starches are mainly responsible in effecting the desired flocculation of iron ores (Houot, 1983).

The major problem seen in these studies relates to maintaining surface properties distinct at fine sizes of below 25 μm (560 mesh). And the efficiency, therefore, depends on the degree of dispersion to prevent

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K. Hanumantha Rao is now with the division of mineral processing, Lulea University of Technology, Lulea, Sweden. **A. Nayak, S.N. Mahapatra,** and **K.S. Narasimhan** are scientists at the Regional Research Laboratory, Council of Scientific and Industrial Research, Orissa, India. SME nonmeeting paper 83-234. Manuscript October 1983. Discussion of this paper must be submitted, in duplicate, prior to Jan. 31, 1986.