Eddy-current separator technology as a novel approach to Alaskan placer gold recovery

D. E. Walsh
Professor, University of Alaska Fairbanks, Fairbanks, Alaska

J.A. Wernham and D.A. Norrgran
Material testing supervisor and technical representative, respectively, Eriez Magnetics, Erie, Pennsylvania

Abstract

A qualitative test program to study placer gold nugget recovery using an eddy-current separator was sponsored jointly by the University of Alaska and Eriez Magnetics. Various gold nuggets from Alaska, ranging in size from 6.4 to 63.5 mm, were tested. All tests were performed using an Eriez Laboratory ESC, Model REA, fitted with a 2,000-gauss, surface field-strength magnetic rotor. The belt speed was set to 91 m/min (300 fpm) and the rotor speed was set to 2,500 rpm in the forward direction. The splitter was adjusted to just reject the largest pieces of rock, which averaged 76 x 102 x 127 mm. Based on the results of this limited test work, it is being recommended to placer gold mine operators that ECS technology is a viable and practical concentration technology for coarse gold recovery. Silver and platinum were also tested.

Key words: Eddy current separator, Placer gold, Magnetic separation

Introduction

During the last 14 years, the Alaskan placer gold mining industry has experienced steep declines in gold production and the number of operating mines. State of Alaska data show a 1988 placer gold production of 265,000 oz from 211 operations and a 2001 placer gold production of less than 23,000 oz from 53 operating mines (Bundtzen et al., 1990; Swainbank et al., 2002). Contributing to the decline during this period were falling gold prices, increasing environmental regulation and a depletion of known placer gold resources. All of these factors place increasing importance on efficient mining and processing practices for placer gold ores.

The efficient recovery of placer gold necessitates an understanding of those factors that significantly influence unit operations and make up the recovery flowsheet. In Alaska, where the sluicebox is the most widely used and the most applicable placer gold concentrator, this means understanding sluice plant design. Above all, proper material sizing, material flow rates and water flow rates are important for maximizing sluicebox performance (Hanneman et al., 1987; Clarkson, 1994; Kelly et al., 1995). Material size and water flow rate are closely related because to move coarser particle sizes through the sluicebox, higher water flow rates are required. Higher water usage also impacts effluent treatment costs, through settling pond area requirements and recycle pumping costs. Hence, there is a real incentive to reduce water usage, and the most efficient means to accomplish this while using a sluicebox is to reduce the material size treated.

Conventional, vibrating screening equipment can size placer materials efficiently, with few operational problems, down to 6.4 mm (1/4 in.). However, operations rarely screen particles this fine because of the coarser, i.e., +6.4 mm (+1/4 in.), gold in the placer ores. More typically, operations screen in the range of 38.1 to 19.1 mm (1 1/2 to 3/4 in.) and accept coarse gold losses above these screen apertures. Even at these coarser sizes, placer gold losses can be significant, as shown by one of the authors (Walsh) for the Valdez Creek Mine (VCM). Figure 1 shows the actual recovered gold size distribution and the estimated, true gold size distribution from VCM's placer ore. Walsh concluded that VCM's gold was normally distributed and that a significant percentage of the gold was coarser than 19.1 mm (3/4 in.) in size — 10% to 15%. Because the VCM produced approximately 100,000 oz of gold per year, 11,100 to 17,650 oz of coarse gold were being lost annually — worth more than $3 million even at today's lower gold prices. Finer screening, to further improve fine gold recovery and reduce water usage, would have resulted in even greater gold losses.

Another extremely important point in this regard is that coarse placer gold commands price premiums in the jewelry and collectable markets. Typically, for each $\sqrt{2}$ size fraction above 2.4 mm (8 mesh), a price premium of $25 to $50/oz applies in the jewelry market (Armstrong, 2001). For example, if the price of gold is $300/oz, then 3.4 x 2.4 mm (6 x 8 mesh) gold would command a price of $350/oz; 4.8 x 3.4 mm (4 x 6 mesh) gold, $400/oz and so on. Very large nuggets (more than several ounces) sold as collectables now fetch

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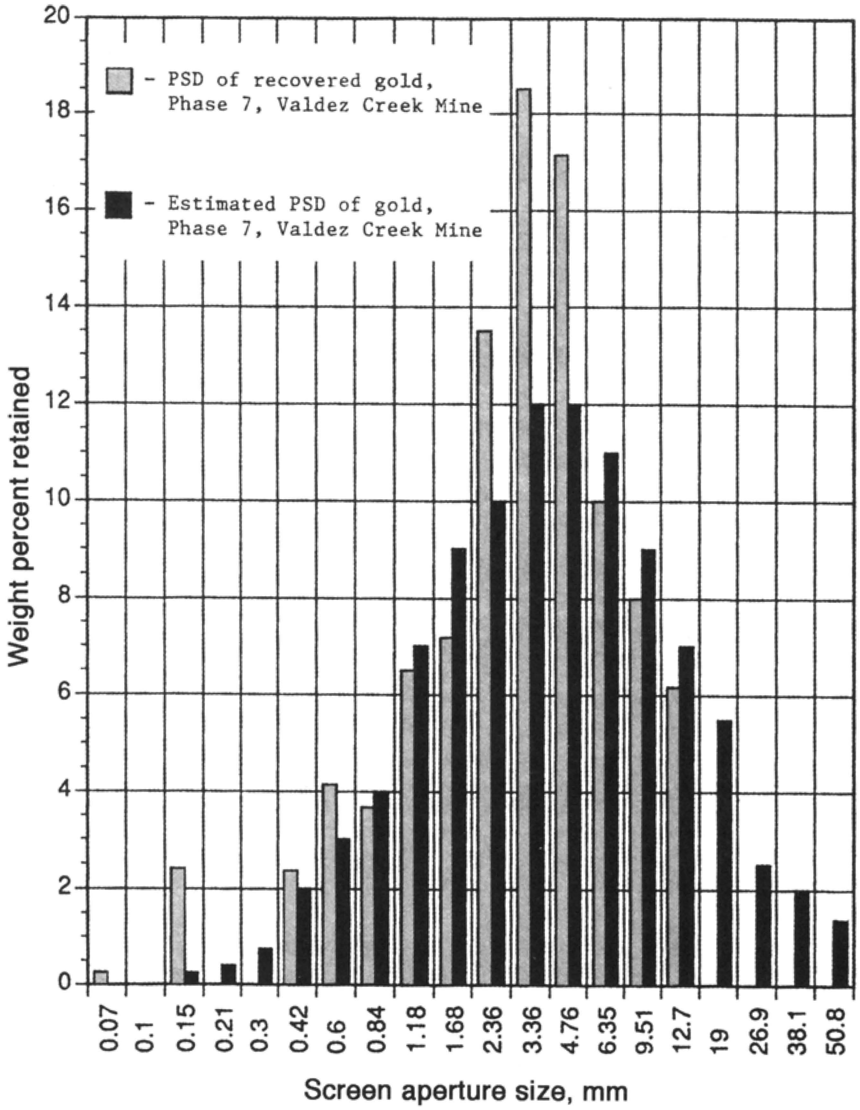

Figure 1 — Recovered and estimated particle-size distributions of gold from Phase 7, Valdez Creek Mine, Alaska.

$1,000 to $2,000/oz. Hence, even though coarse gold may not make up a large percentage of a placer mine's gold reserves, its economic impact would be considerable if it were recovered.

Obviously, what sluice plant operations need is a simple, cost effective way to recover coarse gold from screen oversize material. This would not only allow the operations to screen fine enough to reduce water usage and enhance fine gold recovery, but also to treat the screen oversize material in a separate circuit for coarse gold recovery.

Coarse gold recovery by eddy-current separation

The above discussion demonstrated the need for a unit process capable of recovering coarse placer gold from screen oversize. Unlike the case of fine gold recovery, where a host of concentrators could be considered, few concentrator options are available for treating coarse particle sizes, +12.7 mm (1/2 in.). On-screen jigging and heavy-media processes could handle coarse particle sizes, but they are unsuitable for placer gold operations, where extremely low grades would be experienced, and the latter is too complex of a process. Security issues could also arise with processes requiring considerable space and ancillary unit process. The authors believe that metal detectors could be employed successfully, but to date, few Alaskan operations have utilized them, despite the fact that they are used in the Australian placer gold industry. Observations by one of the authors (Walsh) suggested that a unit known as an eddy-current separator (ECS) has a high probability of meeting coarse-gold recovery requirements of high efficiency and security.

The concept of the alternating magnetic field ECS was developed over a century ago by Thomas Edison, but its application was limited by the rudimentary magnets of the day. With the development of high-strength permanent rare-earth magnetic materials during the 1970s and 1980s, ECS became a very viable separation technology that has been widely applied in recycling and secondary recovery applications. ECS theory has been described adequately in numerous papers elsewhere (Braam et al., 1985; Van Der Valk et al., 1986; Van Der Valk et al., 1987; Braam et al., 1988; Mathier et al., 1990; Norrgran and Wernham, 1991) and is, therefore, not repeated here. Duyvesteyn et al. (1986) demonstrated the potential for gold nugget recovery using the ECS. Their ECS employed rotating, permanent, samarium-cobalt disc magnets. While their approach was successful, the design of their ECS was not a practical arrangement for large tonnage placer gold operations.

Figure 2 illustrates how electric currents are induced in all conductors when exposed to an alternating magnetic field. The induced current generates a magnetic field in the conductor that opposes that of the alternating magnetic field. The net, induced, repulsive force allows separation of conductors from nonconductors.

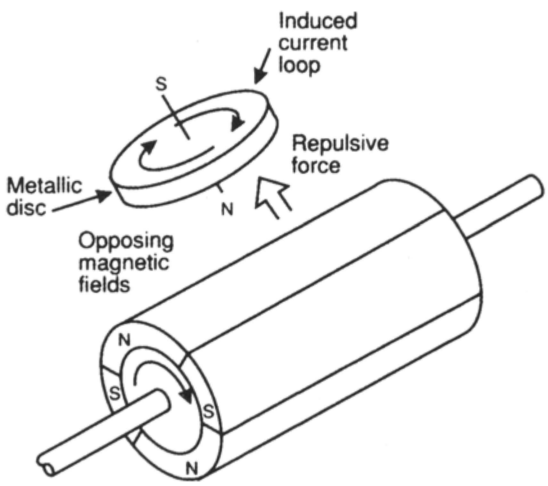

Figure 2 — Schematic representation of generated eddy currents from an alternating field. The magnetic field is produced from rotating permanent magnets.

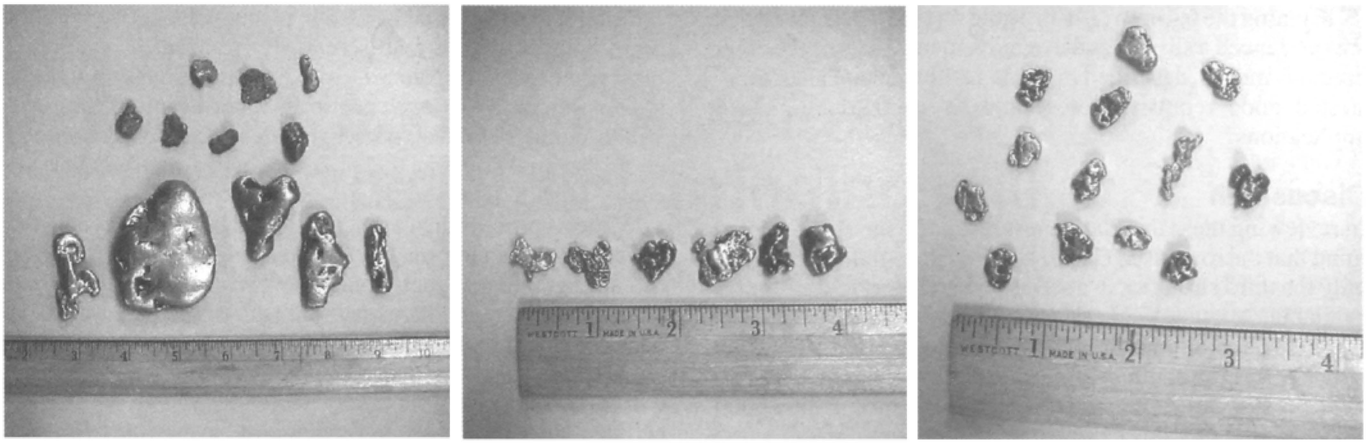

Figure 3 — Examples of gold tested on the eddy-current separator.

Norrgran and Wernham (1991) noted that the ECS was successfully applied in numerous metal sorting and recovery operations. Most common is the sorting of metal from shredded automobile scrap and municipal solid waste. With the advent of high-frequency, high-intensity magnetic fields, the ECS has advanced to the point where it has direct application in the beneficiation of fine sized metals down to 6.4 mm (1/4 in.) (Norrgran and Wernham, 1991).

The utility of the single rotor design shown in Fig. 2 is that it is ideally suited to operate within conveyor-belt systems. Conveyor belts are the most common material-handling units used at Alaskan placer gold mines to transport screen oversize material from the vibrating screen to a waste pile. Gold nuggets discharged from the end of the screen, or a preceding conveyor belt, would pass over the rotating drum of the ECS, where they should achieve an induced magnetic field directly opposed to the alternating magnetic field of the rotor. The repulsive force due to like, opposing, magnetic poles should deflect the gold from the nonconductive waste rock of the screen oversize. An appropriate splitter setting isolates the deflected gold, which is directed into a secure hopper from which it is later retrieved by authorized mine personnel.

Table 1 — Characteristics of precious metals tested on the ECS.

Metal	Description	Mass	Largest two dimensions
Gold	1 - Placer gold nugget	451 g	~51 x 64 mm
Gold	4 - Placer gold nuggets	~53 g each	~25 x 37 mm
Gold	1 - Placer gold nugget	~28 g	~19 x 19 mm
Gold	1 - Placer gold nugget	~8 g	~35 x 3 mm
Gold	1 - Placer gold nugget	~4 g	~19 x 3 mm
Gold	7 - Placer gold nuggets	~4.5 g each	~9 x 16 mm
Gold	6 - Placer gold nuggets	~4.5 g each	~12 x 12 mm
Gold	13 - Placer gold nuggets	~1.7 g each	~6.4 x 6.4 mm
Gold	8 - 1 oz. Krugerand Coins	(per mint specifications)	
Gold	8 - 1 oz. Maple Leaf Coins	(per mint specifications)	
Gold	4 - 1 oz. Englehardt Bars	(per specifications)	
Silver	4 - $1 U.S. Silver Dollars, pre-1900	(per mint specifications)	
Silver	4 - $0.50 U.S. Franklin Coins, pre-960	(per mint specifications)	
Silver	4 - $0.25 U.S. Washington Coins, pre-1960	(per mint specifications)	
Platinum	8 - Dish Crucibles	~2.2 g each	~17.5-mm diam.

Testing

A qualitative test program was sponsored jointly by the University of Alaska (President's Special Projects Fund and UAF Faculty Development Fund) and Eriez Magnetics. A variety of sizes and shapes of gold nuggets, ranging from 6.4 to 63.5 mm (1/4 to 2 1/2 in.), were acquired from Alaskan miners. Photographs of some of the gold nuggets are shown in Fig. 3. The characteristics of the gold are noted in Table 1 along with the characteristics of other precious materials tested. These metals and various sizes of broken rock were transported to Eriez Magnetics' metallurgical laboratory in Erie, Pennsylvania, and tested on the ECS in March 2001.

All testing was performed on Eriez Laboratory ESC, Model REA, fitted with 2,000 gauss, surface field-strength magnetic rotor. Standard settings were used. The belt speed was set to 91 m/min (300 fpm) and the rotor speed was set to 2,500 rpm in the forward direction. The splitter was adjusted to just reject the largest pieces of rock that measured an average 127 x 102 x 76 mm (5 x 4 x 3 in.). One piece of rock was 203 x 127 x 51 mm (8 x 5 x 2 in.).

Individual pieces of placer gold were then tested. All pieces down to and including the 19-mm (3/4-in.) particles easily cleared the splitter. Some of the 12.7-mm (1/2-in.) pieces also cleared the splitter, but most did not. Reversing the rotor did not improve the separation. Based on these observations, the 19-mm (3/4-in.) and larger gold was mixed with 19 x 102-mm (3/4 x 4-in.) rock and tested. The feed rate was set to present a monolayer of particles on the belt and to the separation area. All of the gold was recovered and only two rocks hit the splitter and bounced into the gold split.

Next, the 12.7-mm (1/2-in.) gold was tested against the splitter setting for 19-mm (3/4-in.) rock. Less than one-third of the gold was recovered. Using special extended splitters changed the recovery to two-thirds, but no further improvement could be achieved.

Running the 6.4-mm (1/4-in.) gold on the ECS showed that it experienced a slight repulsive movement. Tests of the other precious metals, described in Table 1, showed that all demonstrated good repulsive forces and had potential for ECS applications.

Discussion

In reviewing these qualitative test results, it should be kept in mind that the rotor used (2,000 gauss surface field strength) is only the third strongest in a series of four rotor field strengths available. A lower field strength ferrite magnetic material is employed for aluminum can separation applications. Two stronger field strength rotors, 3,500 and 4,750 gauss surface field strength, are employed on Eriez Magnetics' Erium 3000 ECS unit and the Super Eddy unit, respectively. Because the repulsive force generated by the ECS is proportional to the square of the field strength experienced by the particles (Norrgran, 1991), gold particles would have experienced three to 5.6 times the force in these stronger field strengths than experienced during testing with the 2,000 gauss rotor. Hence, 6.4-mm (1/4-in.) gold that responded very poorly and 12.7-mm (1/2-in.) gold that responded only moderately during testing may respond quite satisfactorily with a stronger field-strength unit. Tests employing stronger field-strength units were not run due to equipment availability, as well as time and funding constraints.

A rule-of-thumb for ECS applications is that conductors will separate well from nonconductors over a size ratio of 1:4. That is, 25.4-mm (1-in.) conductors should be separable from nonconductors given a feed size range of 25.4 x 102-mm (1 x 4-in.) material to the ECS; 12.7 x 51-mm (1/2 x 2-in.) material is another feed size range example. The gold particles tested in this study appear to follow this rule-of-thumb; 19-mm (3/4-in.) gold being very well separated from 102-mm (4-in.) rock. The treatable size range might be expanded using higher magnetic field strength rotors for placer gold applications.

Based on this limited test work, it can be recommended to placer gold mine operators, that ECS technology is a viable and practical concentration technology for coarse gold recovery. Depending on the coarse gold size distribution in the screen oversize, one or two ECS units may be required. As an example of a placer mine screening at 12.7 mm (1/2 in.) before sluicing, the 12.7 x 51-mm (1/2 x 2-in.) interscreen material would be treated on one ECS, while the plus 51-mm (2-in.) material would require separate treatment on a second ECS. Provision would need to be made to keep very large material, +203-mm (+8-in.), out of the second ECS feed, and tramp iron would need to be removed ahead of both ECS units.

ECS technology could also be applied to underground placer gold mining operations in Alaska, and elsewhere, that operate during winter months. Because gold recovery for these mines is not conducted until summer, due to climatic conditions, they often suffer from cash-flow problems during winter. Current ECS technology could be applied to assist these mines in recovering a portion of the gold values from the ore, the coarse gold, to give them income during winter months. Such gold recovery would take place at below freezing temperatures after autogenous liberation and sizing of coarse gold values in a trommel.

Another application for ECS in placer gold recovery might be to recover coarse gold screened off ahead of pneumatic placer gold recovery plants. Dry jigging operations will achieve higher fine gold recoveries with finer screening of the feed, which could increase coarse gold losses. ECS technology could be used to treat the screen oversize and recover the coarse gold.

Mineral processing engineers should keep their eye on the development of new magnetic materials, which will increase the strength of magnets available for use in eddy-current separators. Increased magnet strength should allow eddy-current separators to treat finer and finer sizes of nonferrous metals, thus opening the door to additional applications of this extremely interesting separation technology. One such application could be their use in final gold recovery (clean up) for both wet and dry placer gold mining operations. Other configurations of the rotating magnets, such as that described by Duyvesteyn et al. (1986), may also extend ECS applications to finer gold size ranges using contemporary commercial strength magnets.

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