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ELUTRIATOR DESIGN MANUAL FOR COARSE HEAVY MINERAL RECOVERY FROM SLUICE BOX CONCENTRATE

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ABSTRACT

This manual addresses the design and fabrication of an elutriation system for the separation of coarse heavy minerals from waste rock. Elutriation is a process for separating a mixture of minerals into two or more products and utilizes the difference in settling velocity between particles to effect this separation. An upward flow of water runs countercurrent to the material flow in a hollow elutriation column. Particle separation is affected by particle density, size and shape and the upward water velocity.

It was felt that the design and demonstration of a low cost, functional and efficient unit for the concentration of coarse, heavy minerals would be of benefit to the placer mining industry. Industrial efficiency can be improved by the additional recovery of by-product heavy minerals with market potential. Elutriation provides an inexpensive method for processing +1/4 inch, sluice box concentrate to recover by-product heavy minerals. Elutriator design emphasized the use of materials which are inexpensive and readily available to the average placer gold mining company. The design also incorporated concentrate storage and shipment functionality into a detachable section of the elutriator.

Design is based on the construction of a prototype unit and testing of the unit for coarse cassiterite (SnO_2) recovery efficiency. Laboratory testing utilized 3/4" x 3/16" sluice box concentrate from Shoreham Resources Ltd's Cache Creek Mine, Tofty, Alaska. Following laboratory testing, the elutriator was field tested on-site in September, 1990.

Both laboratory and field testing were highly successful. The elutriator proved to be a simple, robust concentrator for this application and produced tin recoveries and grades in excess of 99% and 55% respectively. Field feed grades to the elutriation unit were approximately 26% tin.

ACKNOWLEDGEMENTS

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DEFINITION OF SYMBOLS

Symbol	Units	Definition
a,A	mm, µm	Major axis length of particle
b,B	mm, µm	Intermediate axis length of particle
c,C	mm, µm	Minor axis length of particle
C_D	—	Drag coefficient
C_s	mg/liter	Suspended solids concentration
C_w	—	Percent by weight solids concentration
CSF	—	Corey's Shape Factor
d	mm, µm	Spherical particle diameter
d_c	mm, µm	Diameter of a circle equal in area to the largest projected area of a particle
D_c	mm, µm	Diameter of the smallest circle which encloses the largest projected area of a particle
d_n	mm, µm	Nominal diameter. The diameter of a sphere which has a volume equal to that of the particle
D	cm, mm	Inside diameter of a pipe, tube, etc.
(dv/dy)	sec^{-1}	Shear rate
F	lb/100 ft^2	Fann shear stress
g	cm/sec^2	Acceleration of gravity
h	cm, mm	Height above a referenced datum
Δh	cm, mm	Fall distance
K	—	Heywood's volume constant
K_f	—	Coefficient of flattening defined by Saks

DEFINITION OF SYMBOLS

Symbol	Units	Definition
n	—	Number of observations
Q	cm^3/sec	Volume flow rate
R	rpm	Fann shear rate
Re	—	Reynolds number
t	sec	Time interval
$t(\alpha/2(x),\nu)$	—	Student's t score at level of significance $(\alpha/2(x))$ and ν degrees of freedom
V_t	cm/sec	Terminal settling velocity
V_Q	cm/sec	Flow velocity
x	—	Variable coefficients
α	—	Statistical level of significance
γ_m	—	Specific gravity of a suspension
γ_s	—	Specific gravity of a solid
μ	centipoise $(gm/cm \cdot s)x10^{-2}$	Dynamic viscosity
μ_a	centipoise	Apparent dynamic viscosity at shear rate, dv/dy
ν	—	Statistical degrees of freedom
π	—	Pi
ρ_l	$gram/cm^3$	Density of liquid
ρ_m	$gram/cm^3$	Density of suspension
ρ_s	$gram/cm^3$	Density of solid
τ	$dynes/cm^2$	Shear stress

INTRODUCTION

Elutriation is a process for separating a mixture of mineral grains into two or more products by virtue of their respective settling velocities in a fluid; water in this instance (Figure 1). Elutriation theory is based on the laws of fluid mechanics. These laws are derived for spherical particles and consider a balance of buoyant, gravitational, and viscous drag forces acting upon particles.

Stokes' Law states that settling velocity increases proportionally to the square of the diameter of the particle. With decreasing particle size the settling velocity drops off very rapidly. Settling velocity also varies with density. This law is applicable for particles with Reynolds numbers (Re) less than one; for particles so small that the liquid flows around them in a laminar fashion.

$$\mathrm{Re} = \frac{V_t d \rho_l}{\mu} \qquad \text{Eq. 1}$$

Stokes' Law is then stated as:

$$V_t = \frac{g(\rho_s - \rho_l)\, d^2}{18\mu} \qquad \text{Eq. 2}$$

Newton's Law applies to coarser spherical particles that settle in the turbulent flow regime. Newton's Law states that terminal velocity varies proportionally to the square root of the diameter of a particle. Consequently, changes in settling velocity are not as rapid with particle size changes as they are with Stokes' Law. This law applies to particles with Reynolds numbers greater than 1,000. For Newton's Law:

$$V_t = \left[\frac{3.33\, g(\rho_s - \rho_l) d}{\rho_l}\right]^{1/2} \qquad \text{Eq. 3}$$

Between the ranges of Stokes' Law and Newton's Law, there is no single equation that can be applied to calculate settling velocity. Such settling velocities can be determined indirectly, by iteration, using the equation:

$$V_t = \left[\frac{4g(\rho_s - \rho_l) d}{3\, C_D \rho_l}\right]^{1/2} \qquad \text{Eq. 4}$$

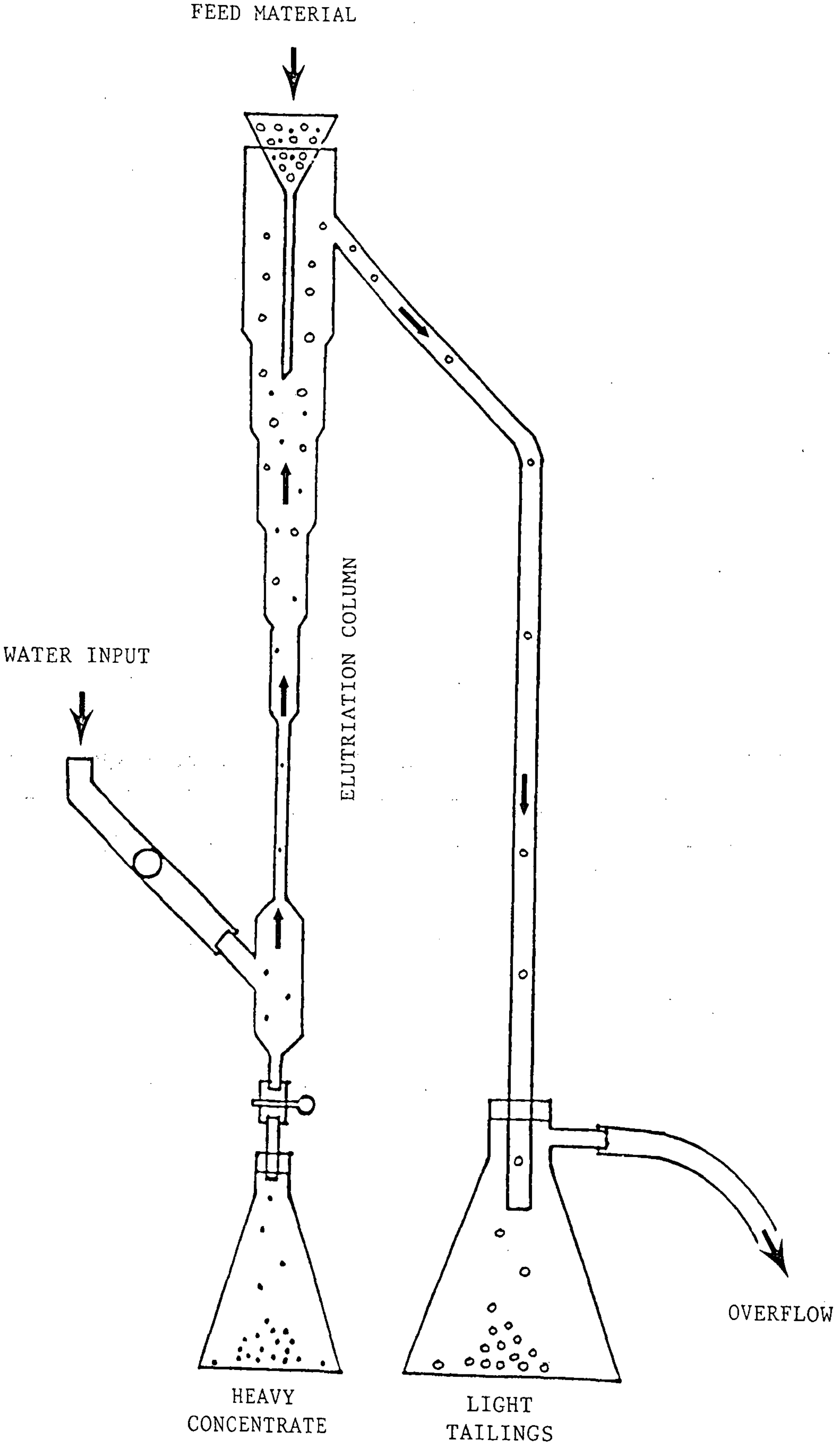


Figure 1. The process of Elutriation.

The drag coefficient, C_D, is a function of particle shape and the flow characteristics about the particle. Values of C_D are generally available in graphical form as plots of C_D vs. the Reynolds number for given particle shapes.

These laws show that the terminal velocity of a spherical mineral particle in a particular fluid is a function only of the particle size and density. It can be seen that:

1. If two particles have the same density, then the particle with the larger spherical diameter has the higher settling velocity.
2. If two particles have the same spherical diameter, then the denser particle has the higher settling velocity.

Not only do the size and specific gravity of a mineral grain affect its settling velocity, but shape too has a pronounced influence. Several ways exist of describing the non-sphericity of particles and the more common ones are listed below. In describing these, the following convention of particle dimensions is adopted: $A \geq B \geq C$, so that for nonequidimensional grains, C corresponds to the grain thickness and A and B dimension of the grain's surface of largest projected area.

(1) The Flatness Factor (Lashley, 1983) is defined as: $FF=(A+B)/2C$ and can be thought of as the arithmetic average of the two largest dimensions divided by the particle thickness. The flatness factor equals 1 for a sphere or cube and gets progressively larger as particles become flattened.

(2) Heywood's (1933) shape constant(10), K:

$$K = \frac{\text{Particle Volume}}{(\text{projected diameter})^3}$$

where the projected diameter is defined as $(4(AB)/\pi)^{0.5}$. K equals 0.524 for a sphere and becomes smaller as the flatness of the particle increases.

(3) Coefficient of flattening, K_f, is defined by Saks (1974) as:

$$K_f = \sqrt{AB}/C.$$

(4) Corey's Shape Factor (Corey, 1949) is defined as $C.S.F. = C/\sqrt{AB}$ and can be thought of as the particle thickness divided by the geometric average of the particle's other two dimensions. Corey's shape factor equals 1 for a cube or sphere and decreases as the flatness of a grain increases.

Albertson (1954) concluded that while it was unlikely that particle shape could ever be fully described by a single parameter, Corey's shape factor adequately described particle shape to the degree of refinement required to discuss a particle's shape influence on settling velocity. The author of the present study chose to use Corey's shape factor for the above quoted reasons and because Corey's shape factor has consistently been used in previous MIRL studies involving gold shape since 1973.

The effect of particle shape on the settling velocity of constant mass particles can be seen by examining Figure 2. These data, compiled by Corey (1949), shows that sand particles with a Corey shape factor of 0.85 have an average terminal settling velocity of nearly twice that seen for sand particles of shape factor 0.35. Spherical sand particles settled at velocities three times those observed for particles of 0.35 shape factor. With respect to the effect of shape on the settling velocity of gold particles, Walsh (1988) has experimentally determined the data shown in Figures 3 and 4.

Thus, a third rule can be added to those previously noted above:

3. If two particles have the same density and diameter, then the particle with the higher Corey shape factor has the higher settling velocity.

Settling velocity equations and rules are summarized in the appendix, "Settling Velocity Summary Sheet," page 38.

The application and design of the elutriation system emphasized in this manual are for the separation of coarse particles that have settling velocities in the Newtonian range. Minus 1/4 mesh sluice box concentrate can be upgraded efficiently by several processes including spinning bowls, jigs, tables, etc. However, these units are not applicable for +1/4 inch feed materials; hence the emphasis of this manual. In fact, elutriation as a separation process, becomes less attractive for finer particles. This can be seen by considering two mineral particles of densities ρ_a and ρ_b and diameters d_a and d_b respectively, falling in water of density ρ_w, at exactly the same settling rate. Their terminal velocities must be the same, and hence from the previously discussed settling velocity equations:

$$\frac{d_a}{d_b} = \left(\frac{\rho_b - \rho_w}{\rho_a - \rho_w}\right)^n \qquad \text{Eq. 5}$$

where: $n = 1$ for Newtonian Settling
$n = 1/2$ for Stokes Settling
$1/2 \leq n \leq 1$ for Transitional Settling

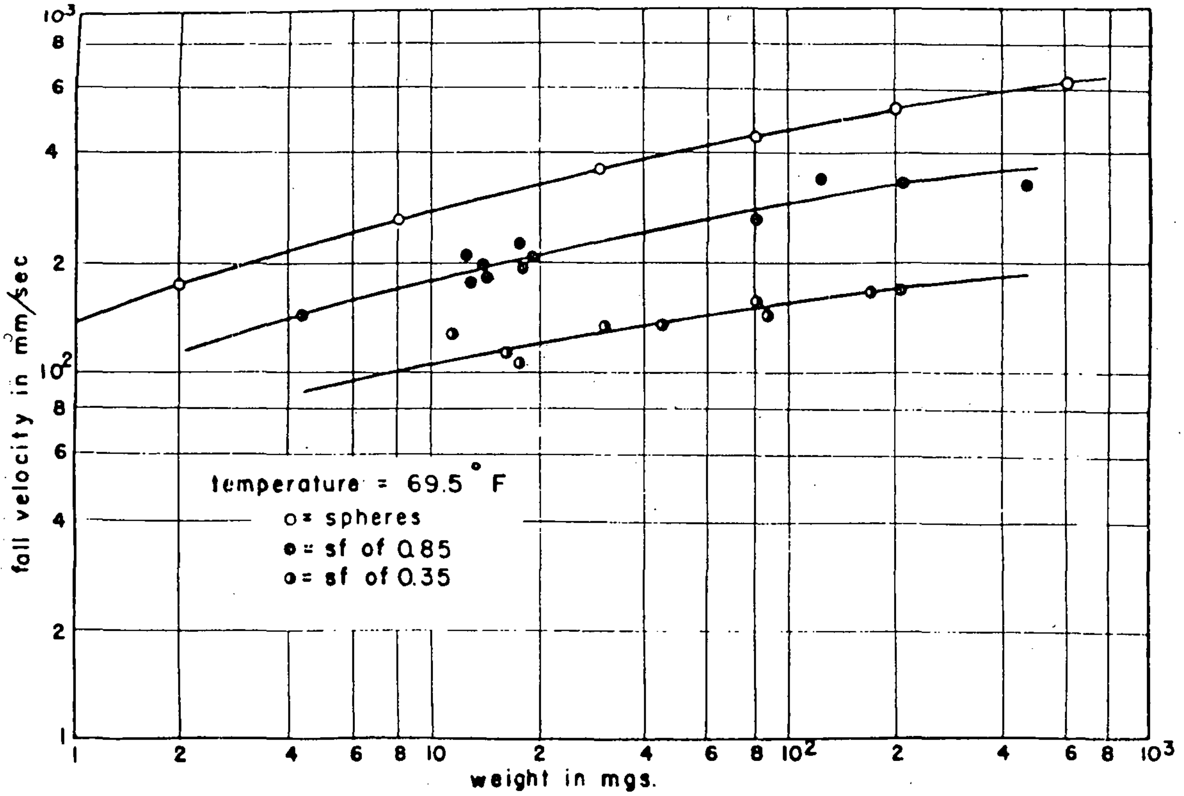


Figure 2. Fall velocity as a function of particle shape and mass (Corey, 1949).

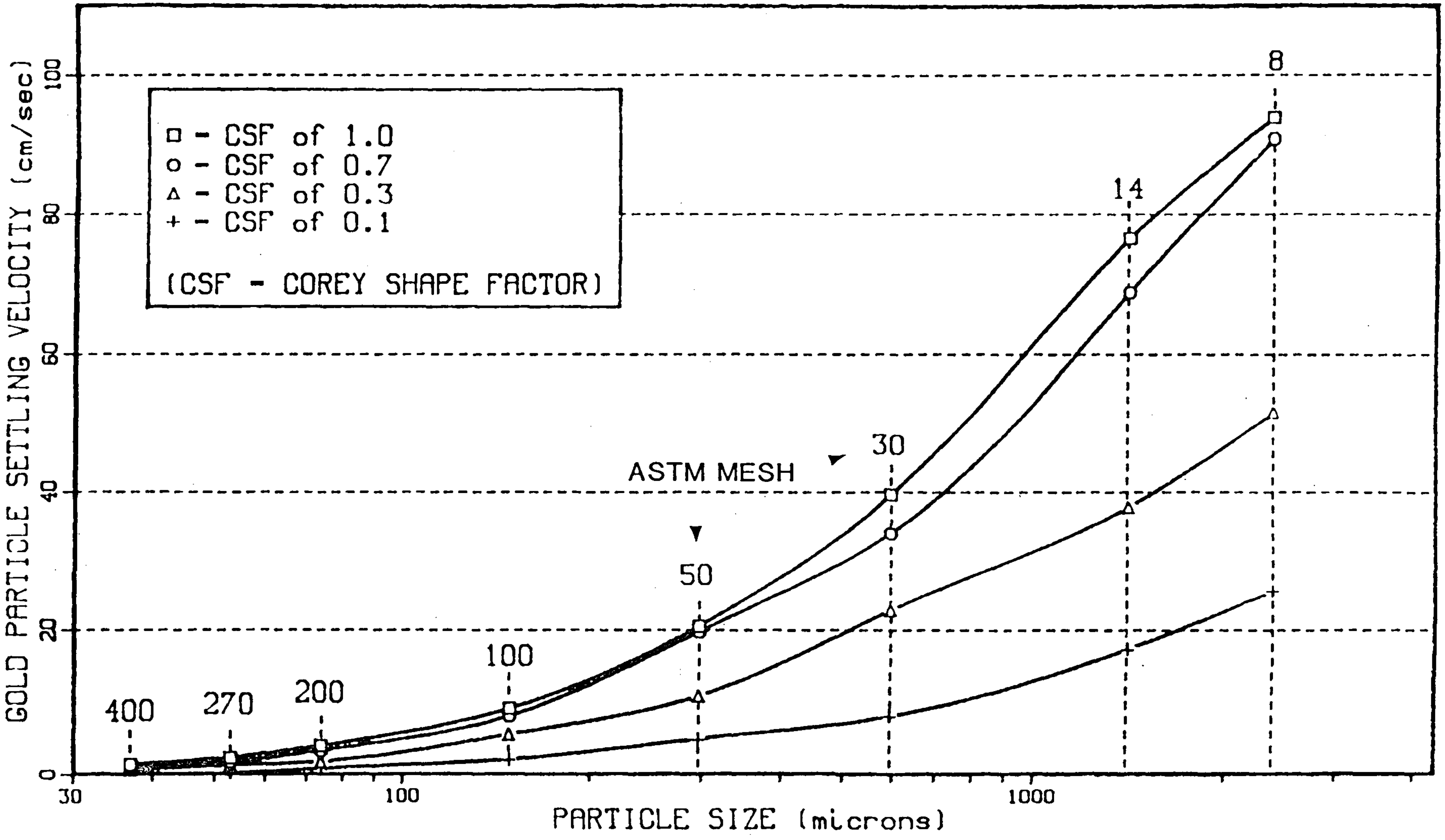


Figure 3. Settling velocities for gold particles of various sizes and flatnesses

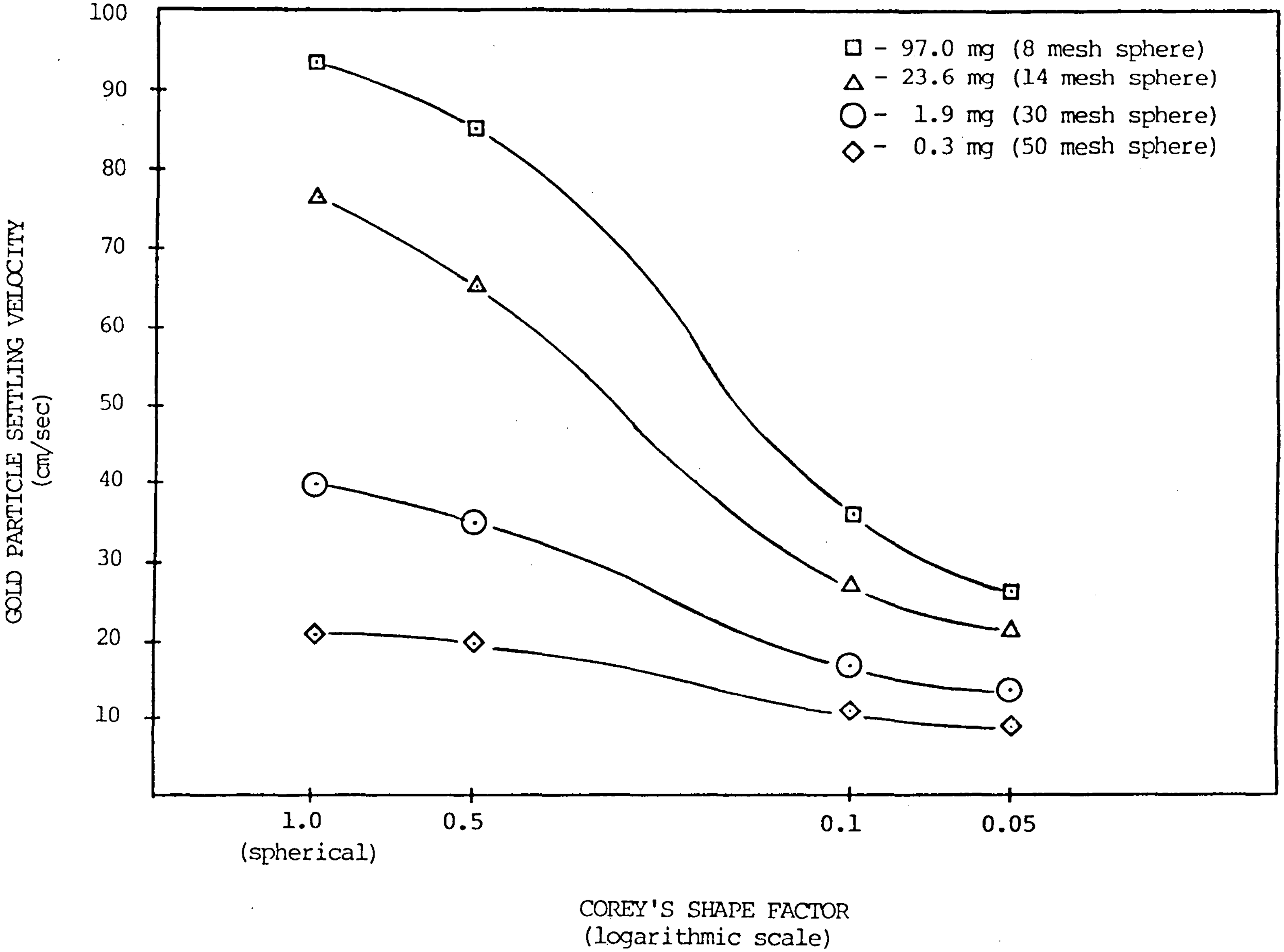


Figure 4. Settling velocities for gold particles of constant mass at various flatnesses (97 mg to 0.3 mg).

This expression, known as the free settling ratio, is the ratio of particle size required for two minerals of different densities to settle at equal velocities.

As an example let's consider the separation of pure quartz, ($\rho_q = 2.7$) from pure cassiterite ($\rho_c = 7.0$). Substituting these values and $\rho_w = 1$ into Eq. 5 yields;

$$\frac{da}{db} = \left(\frac{7\text{-}1}{2.7\text{-}1}\right)^n = \left(\frac{6}{1.7}\right)^n$$

$$\text{or:}\quad \frac{da}{db} = \begin{array}{l} 3.5 \text{ for Newtonian Settling} \\ 1.9 \text{ for Stokes Settling} \\ 1.9 < da/db < 3.5 \text{ for Transitional Settling} \end{array}$$

The Newtonian value of 3.5 indicates that a 3.5 mm sphere of quartz will settle through water at the same velocity as a 1 mm diameter sphere of cassiterite. The Stokes value of 1.9 indicates that a 100 µm sphere of quartz and a 53 µm sphere of cassiterite have equal settling velocities. This implies that a broader size range of Newtonian (coarse) setting particles can be efficiently treated by elutriation than fine particles with Stokes settling characteristics. Hence, one gets more "bang for the buck" when elutriation is used for upgrading coarse size fractions of minerals. Table 1 presents Newtonian settling velocity data versus particle size and specific gravity for spherical particles. Like the Newtonian free settling ratio, this table can be used to estimate treatable size ranges.

In the case of the test work performed as a basis for this design manual, a 1-1/4 x 1/4 inch material size fraction was successfully treated by elutriation to separate Tofty, Alaska cassiterite ($\rho = 5.5$) from waste shale ($\rho = 2.5$). However, in the case of the Tofty materials, particle shape also favors the separation of cassiterite from shale. While the cassiterite is dense and chunky (high CSF), the shale is light and platy (low CSF).

It is this author's opinion that most placer gold mine operators may be familiar with elutriation from having attempted to use it to separate fine gold from black sands. In this application, elutriation is not an effective process unless very narrow size fractions of material are treated. Though there is a large density difference between the gold ($\rho \cong 17$) and black sands ($\rho \cong 5$), working against this separation by elutriation are the size of the material treated (free settling ratio exponent, n, less than 1) and the negative impact of particle shape (flaky gold vs. chunky black sands). Such experience should not cause the mine operator to discount the use of elutriation for the treatment of coarse minerals,

Table 1. Settling Velocity (ft/sec) as a function of particle size (inches) and specific gravity.

Particle Size	SPECIFIC GRAVITY OF PARTICLE									
(Inches)	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	17.0
1/8	1.29 $\frac{ft}{sec}$	1.49	1.67	1.83	1.97	2.11	2.36	2.59	2.79	4.22
1/4	1.82	2.10	2.36	2.58	2.79	2.99	3.34	3.66	3.94	5.97
1/2	2.58	2.98	3.34	3.65	3.95	4.22	4.73	5.17	5.57	8.45
3/4	3.16	3.65	4.09	4.47	4.84	5.17	5.79	6.34	6.83	10.34
1	3.64	4.21	4.72	5.16	5.58	5.97	6.69	7.32	7.88	11.94
1-1/2	4.46	5.16	5.78	6.33	6.84	7.31	8.19	8.96	9.66	14.93

especially where the shape effect is neutral to positive. As will be seen later in this manual, elutriation can be extremely efficient under certain circumstances.

ELUTRIATOR DESIGN

From the discussion of the previous section, the reader can appreciate that the design of a simple elutriator for the separation of minerals of different densities requires determination of the following:

1) Densities range of materials to be treated.
2) Size range of materials to be treated.
3) Shapes range of materials to be treated.

Densities of the various mineral species to be separated can be determined using the worksheet provided in the appendix, Density Determination Worksheet, page 39. The process is a simple one that employs assumptions valid for the accuracy required for initial design. Basically, the procedure requires a container of known volume and a balance for weighing. The accuracy of the procedure will be improved if a good sample of particles of each material is utilized. The author would recommend at least 50-100 particles.

Once the densities of the different materials are known, the free settling ratio can be used to determine the feasible size ranges for separation. Alternatively, tables 2 - 11 can be used. Each table shows Newtonian settling velocities for particle sizes from 1/8 inch through 1-1/2 inches. Various densities are considered over tables 2 - 11. Thus for the sake of example, if one were interested in separating spherical particles of densities 2.5 and 8.0, tables 2 and 10 would be used. If the smallest particle of 8.0 specific gravity (s.g.) material to be processed were 1/4 inch, the settling velocity would be read from table 10 as 3.94 ft/sec. Then, turning to Table 2, column 2 would be run down until a value near 3.94 ft/sec were encountered. In this case 3.94 ft/sec lies between the settling velocities for 1 inch and 1-1/2 inch 2.5 specific gravity material. Hence, one might estimate that a size fraction of 1/4 x 1-1/4 inches could be successfully treated by elutriation. If it were desired to treat a broader size range than indicated treatable by the tables or free settling ratio, then perhaps multiple passes through the elutriator with separate size fractions would be required.

The settling velocities may need to be modified if an inspection of the different materials indicates that there is a significant departure from a spherical or cubic shape. Table 12 is supplied for this purpose and relates Corey shape factor to a correction factor to

Table 2. Settling velocities (ft/sec) for various size particles ($\rho_s = 2.5$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	1.29	3.2 gpm	7.1	12.6	28.4	50.5
1/4	1.82	4.5	10.0	17.8	40.1	71.3
1/2	2.58	-	14.2	25.2	56.8	100.9
3/4	3.16	-	-	30.9	69.5	123.6
1	3.64	-	-	-	80.3	142.7
1-1/2	4.46	-	-	-	-	174.8

Notes:
1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98)\ (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 3. Settling velocities (ft/sec) for various size particles ($\rho_s = 3.0$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	1.49	3.6 gpm	8.2	14.6	32.8	58.3
1/4	2.10	5.2	11.6	20.6	46.4	82.5
1/2	2.98	-	16.4	29.2	65.6	116.6
3/4	3.65	-	-	35.7	80.3	142.8
1	4.21	-	-	-	92.8	164.9
1-1/2	5.16	-	-	-	-	202.0

Notes:
1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98)\ (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 4. Settling velocities (ft/sec) for various size particles ($\rho_s = 3.5$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	1.67	4.1 gpm	9.2	16.3	36.8	65.3
1/4	2.36	5.8	13.0	23.1	52.0	92.4
1/2	3.34	-	18.4	32.7	73.5	130.7
3/4	4.09	-	-	40.0	90.0	160.1
1	4.72	-	-	-	103.9	184.8
1-1/2	5.78	-	-	-	-	226.3

Notes:
1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98)\ (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 5. Settling velocities (ft/sec) for various size particles ($\rho_s = 4.0$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	1.82	4.5 gpm	10.1	17.9	40.2	71.5
1/4	2.58	6.3	14.2	25.3	56.9	101.2
1/2	3.65	-	20.1	35.8	80.5	143.1
3/4	4.47	-	-	43.8	98.6	175.2
1	5.16	-	-	-	113.8	202.3
1-1/2	6.33	-	-	-	-	247.8

Notes:
1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98)\ (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 6. Settling velocities (ft/sec) for various size particles ($\rho_s = 4.5$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	1.97	4.8 gpm	10.8	19.3	43.5	77.3
1/4	2.79	6.8	15.4	27.3	61.5	109.4
1/2	3.95	-	21.8	38.7	87.0	154.7
3/4	4.84	-	-	47.4	106.5	189.4
1	5.58	-	-	-	123.0	218.7
1-1/2	6.84	-	-	-	-	267.9

Notes:

1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98) (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 7. Settling velocities (ft/sec) for various size particles ($\rho_s = 5.0$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	2.11	5.2 gpm	11.6	20.7	46.5	82.7
1/4	2.99	7.3	16.4	29.2	65.8	117.0
1/2	4.22	-	23.3	41.4	93.0	165.4
3/4	5.17	-	-	50.6	113.9	202.6
1	5.97	-	-	-	131.6	233.9
1-1/2	7.31	-	-	-	-	286.5

Notes:

1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98) (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 8. Settling velocities (ft/sec) for various size particles ($\rho_s = 6.0$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	2.36	5.8 gpm	13.0	23.2	52.1	92.6
1/4	3.34	8.2	18.4	32.7	73.7	131.0
1/2	4.73	-	26.0	46.3	104.2	185.3
3/4	5.79	-	-	56.7	127.6	226.9
1	6.69	-	-	-	147.4	262.0
1-1/2	8.19	-	-	-	-	320.9

Notes:
1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98)\ (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 9. Settling velocities (ft/sec) for various size particles ($\rho_s = 7.0$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	2.59	6.3 gpm	14.2	25.3	57.0	101.3
1/4	3.66	8.9	20.1	35.8	80.6	143.3
1/2	5.17	-	28.5	50.6	114.0	202.6
3/4	6.33	-	-	62.0	139.6	248.2
1	7.32	-	-	-	161.2	286.6
1-1/2	8.96	-	-	-	-	351.0

Notes:
1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98)\ (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 10. Settling velocities (ft/sec) for various size particles ($\rho_s = 8.0$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	2.79	6.8 gpm	15.3	27.3	61.4	109.2
1/4	3.94	9.6	21.7	38.6	86.8	154.4
1/2	5.57	-	30.7	54.6	122.8	218.4
3/4	6.83	-	-	66.8	150.4	267.4
1	7.88	-	-	-	173.7	308.8
1 1/2	9.66	-	-	-	-	378.2

Notes:

1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98)\ (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 11. Settling velocities (ft/sec) for various size particles ($\rho_s = 17.0$) and equivalent flowrates (gpm) through various diameter pipes.

Particle Size (Inches)	Settling Velocity (ft/sec)	Pipe Inside Diameters (Inches)				
		1	1.5	2.0	3.0	4.0
1/8	4.22	10.3 gpm	23.3	41.4	93.0	165.4
1/4	5.97	14.6	32.9	58.5	131.6	233.9
1/2	8.45	-	46.5	82.7	186.1	330.8
3/4	10.34	-	-	101.3	227.9	405.2
1	11.94	-	-	-	263.1	467.9
1 1/2	14.63	-	-	-	-	573.0

Notes:

1) Settling velocities were calculated from Newton's Law using the simplified form; $V_t = (2.98)\ (d(\rho_s - 1))^{1/2}$, where d is in inches.
2) Corey Shape Factor of 1 assumed for particle shape.

Table 12. Settling Velocity Reduction Factors for Particles with Corey Shape Factors less than 1.

CSF	Reduction Factor
1.0	None
0.7	0.9
0.6	0.8
0.5	0.7
0.4	0.6
0.3	0.5
0.2	0.4
0.1	0.25

Note: For coarse particles with CSFs of 0.7 or less, multiply the spherical settling velocity by the reduction factor to approximate the settling velocity of the non-spherical particle.

Example: Determine V_t for a 1/2 inch, 3.0 s.g. particle with a CSF of 0.5.

V_t (spherical) $= 2.98 \frac{\text{ft}}{\text{sec}}$ (from Table 3, page 11).

V_t (CSF = 0.5) = 2.98 (Reduction Factor for CSF = 0.5)

= 2.98 (0.7)

= 2.1 ft/sec

be applied to the calculated or tabulated settling velocity. For instance, in the above example, had the 8.0 s.g. material been nearly spherical and the 2.5 s.g. material had an average shape factor of approximately 0.7, then the settling velocity values of Table 2, column 2 would need to be multiplied (adjusted downwards) by the factor, 0.9. Since 4.46 ft/sec multiplied by 0.9 equals 4.01 ft/sec, is very nearly equal to 3.94, the settling velocity of the 1/4 inch, 8.0 s.g. material, the size range of elutriatable material is extended by the reduced shape factor of the less dense material. Dissimilarly, the size range of the treatable material would be reduced if the shape factor of the denser material is less than the shape factor of the less dense material. If both materials' shape factors depart equally from unity, no correction needs to be applied in determining the size range treatable. A good example of the shape effect was observed for the case of elutriating dense, chunky cassiterite from Tofty, Alaska from light, platy, shale. The elutriatable size range was extended from the 1/4 x 3/4 inch indicated from the free setting ratio to 1/4 x 1-1/4 inches due to the flaky nature of the less dense material.

Once density, size and shape of the material to be treated have been determined the actual hardware of the elutriator can be specified. The topsize of the material treated should be used to specify the minimum dimension of the elutriator piping itself. A good "rule of thumb" to use here is that the inside pipe diameter should be at least 3 times the diameter of the largest particle. This factor may be reduced to 2.5 if there is very little of the coarse material in the feed to the elutriator. Hence, a 1 inch topsize feed to an elutriator system would require that a 2.5-3.0 inch pipe be used. Tables 2 - 11 are again useful here. They show equivalent settling velocity values as gpm flowrates through various, acceptable diameter pipes for numerous sizes and densities of material.

Additional flowrate (gpm) versus settling velocity data for various diameter pipes are shown in Table 13. These flowrate values should be adjusted for shape factor departures from unity if significant. The values of Table 12 can be used for this purpose. If spherical particle flowrate values are used where inappropriate, coarser size material will be rejected via the elutriator overflow.

ELUTRIATOR CONSTRUCTION

Conceptually, the elutriator was viewed as being mounted on a lid interchangeable to a number of recyclable containers (Figure 5). This would allow the heavy minerals to collect as a concentrate below the elutriator. When the concentrate container is filled, the elutriator and mounting plate would be shifted to another receptacle, while the full concentrate container would be sealed and ready for shipment. Figure 6 shows the elutriator constructed at MIRL for the test work using Tofty cassiterite and Figure 7 shows a schematic of its component parts. Table 14 presents the 1990 U.S. dollar, retail cost of each part. The total cost of MIRL's, 3 inch ABS pipe elutriator was $120.

The size of the elutriator concentrate container will be a function of the batch size of material processed. For small batches, a 5 gallon bucket may be adequate. A 55 gallon drum is the largest size receptacle anticipated for the intended elutriator application as a cleanup unit. Table 14 lists a variety of alternate receptacle options and their price.

Table 13. Settling Velocity (ft/sec) related to flow rates (gpm) through various diameter pipes.

Settling Velocity (ft/sec)	Pipe Inside Diameters (inches)				
	1.0	1.5	2.0	3.0	4.0
1.0	2.4 gpm	5.5	9.8	22.0	39.2
1.1	2.7	6.0	10.8	24.2	43.1
1.2	2.9	6.6	11.7	26.4	47.0
1.3	3.2	7.2	12.7	28.6	50.9
1.4	3.4	7.7	13.7	30.8	54.8
1.5	3.7	8.3	14.7	33.0	58.7
1.6	3.9	8.8	15.7	35.2	62.7
1.7	4.2	9.4	16.6	37.4	66.6
1.8	4.4	9.9	17.6	39.6	70.5
1.9	4.6	10.5	18.6	41.8	74.4
2.0	4.9	11.0	19.6	44.1	78.3
2.1	5.1	11.6	20.6	46.3	82.2
2.2	5.4	12.1	21.5	48.5	86.2
2.3	5.6	12.7	22.5	50.7	90.1
2.4	5.9	13.3	23.5	52.9	94.0
2.5	6.1	13.8	24.5	55.1	97.9
2.6	6.4	14.3	25.4	57.3	101.8
2.7	6.6	14.9	26.4	59.5	105.7
2.8	6.8	15.4	27.4	61.7	109.7
2.9	7.1	16.0	28.4	63.9	113.6
3.0	7.3	16.5	29.4	66.1	117.5
3.1	7.6	17.1	30.3	68.3	121.4
3.2	7.8	17.6	31.3	70.5	125.3
3.3	8.1	18.2	32.3	72.7	129.3
3.4	8.3	18.7	33.3	74.9	133.2
3.5	8.6	19.3	34.3	77.1	137.1
3.6	8.8	19.8	35.2	79.3	141.0
3.7	9.0	20.4	36.2	81.5	144.9
3.8	9.3	20.9	37.2	83.7	148.8
3.9	9.5	21.5	38.2	85.9	152.8
4.0	9.8	22.0	39.2	88.1	156.7
4.1	10.0	22.6	40.1	90.3	160.6
4.2	10.3	23.1	41.1	92.5	164.5
4.3	10.5	23.7	42.1	94.7	168.4
4.4	10.8	24.2	43.1	96.9	172.3
4.5	11.0	24.8	44.1	99.1	176.3
4.6	11.3	25.3	45.0	101.3	180.2
4.7	11.5	25.9	46.0	103.5	184.1
4.8	11.7	26.4	47.0	105.7	188.0
4.9	12.0	27.0	48.0	107.9	191.9
5.0	12.2	27.5	49.0	110.1	195.8
5.1	12.5	28.1	49.9	112.3	199.8
5.2	12.7	28.6	50.9	114.5	203.7
5.3	13.0	29.2	51.9	116.8	207.6

Table 13. (continued)

Settling Velocity (ft/sec)	Pipe Inside Diameters (inches)				
	1.0	1.5	2.0	3.0	4.0
5.4	13.2 gpm	29.7	52.9	119.0	211.5
5.5	13.5	30.3	53.8	121.2	215.4
5.6	13.7	30.8	54.8	123.4	219.3
5.7	13.9	31.4	55.8	125.6	223.3
5.8	14.2	31.9	56.8	127.8	227.2
5.9	14.4	32.5	57.8	130.0	231.1
6.0	14.7	33.0	58.7	132.2	235.0
6.1	14.9	33.6	59.7	134.4	238.9
6.2	15.2	34.1	60.7	136.6	242.8
6.3	15.4	34.7	61.7	138.8	246.8
6.4	15.7	35.2	62.7	141.0	250.7
6.5	15.9	35.8	63.6	143.2	254.6
6.6	16.1	36.3	64.6	145.4	258.5
6.7	16.4	36.9	65.6	147.6	262.4
6.8	16.6	37.4	66.6	149.8	266.3
6.9	16.9	38.0	67.6	152.0	270.3
7.0	17.1	38.5	68.5	154.2	274.2
7.1	17.4	39.1	69.5	156.4	278.1
7.2	17.6	39.6	70.5	158.6	282.0
7.3	17.9	40.2	71.5	160.8	285.9
7.4	18.1	40.7	72.5	163.0	289.8
7.5	18.4	41.3	73.4	165.2	293.8
7.6	18.6	41.9	74.4	167.4	297.7
7.7	18.8	42.4	75.4	169.6	301.6
7.8	19.1	43.0	76.4	171.8	305.5
7.9	19.3	43.5	77.3	174.0	309.4
8.0	19.6	44.1	78.3	176.2	313.4
8.1	19.8	44.6	79.3	178.4	317.3
8.2	20.1	45.2	80.3	180.6	321.2
8.3	20.3	45.7	81.3	182.8	325.1
8.4	20.6	46.3	82.2	185.0	329.0
8.5	20.8	46.8	83.2	187.2	332.9
8.6	21.0	47.4	84.2	189.4	336.9
8.7	21.3	47.9	85.2	191.7	340.8
8.8	21.5	48.5	86.2	193.9	344.7
8.9	21.8	49.0	87.1	196.1	348.6
9.0	22.0	49.6	88.1	198.3	352.5
9.1	22.3	50.1	89.1	200.5	356.4
9.2	22.5	50.7	90.1	202.7	360.4
9.3	22.8	51.2	91.1	204.9	364.3
9.4	23.0	51.8	92.0	207.1	368.2
9.5	23.2	52.3	93.0	209.3	372.1
9.6	23.5	52.9	94.0	211.5	376.0
9.7	23.7	53.4	95.0	213.7	379.9
9.8	24.0	54.0	96.0	215.9	383.9
9.9	24.2	54.5	96.9	218.1	387.8
10.0	24.5	55.1	97.9	220.3	391.7

Table 13. (continued)

Settling Velocity (ft/sec)	Pipe Inside Diameters (inches)				
	1.0	1.5	2.0	3.0	4.0
11.0	26.9 gpm	60.6	107.7	242.3	430.9
12.0	29.4	66.1	117.5	264.4	470.0
13.0	31.8	71.6	127.3	286.4	509.2
14.0	34.3	77.1	137.1	308.4	548.4
15.0	36.7	82.6	146.9	330.4	587.5

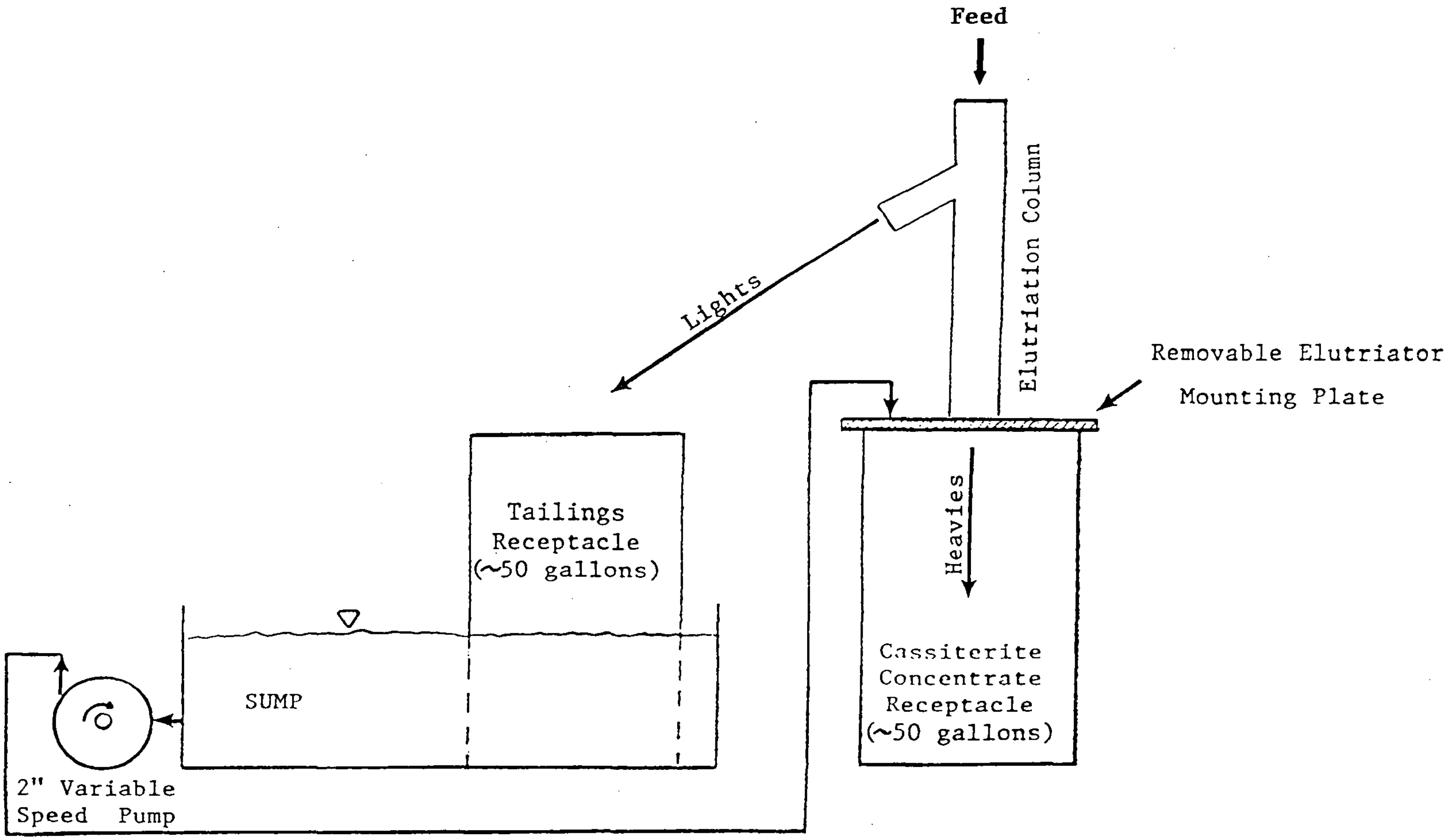


Figure 5. Conceptual Layout of Proposed Elutriation System.
(Not to scale)

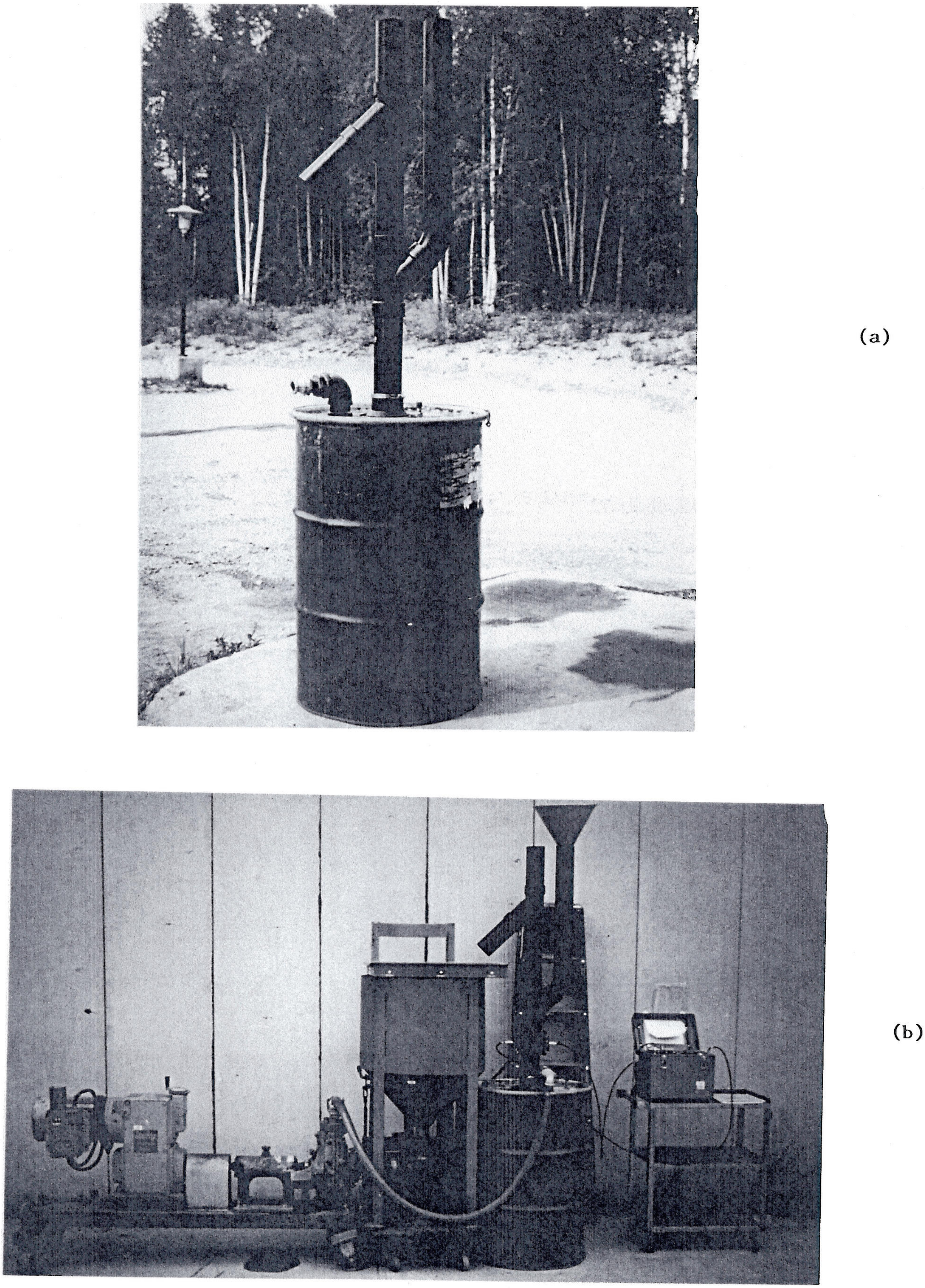


Figure 6. MIRL's elutriator. (a) Final design and (b) Closed-circuit elutriator system used for laboratory test work.

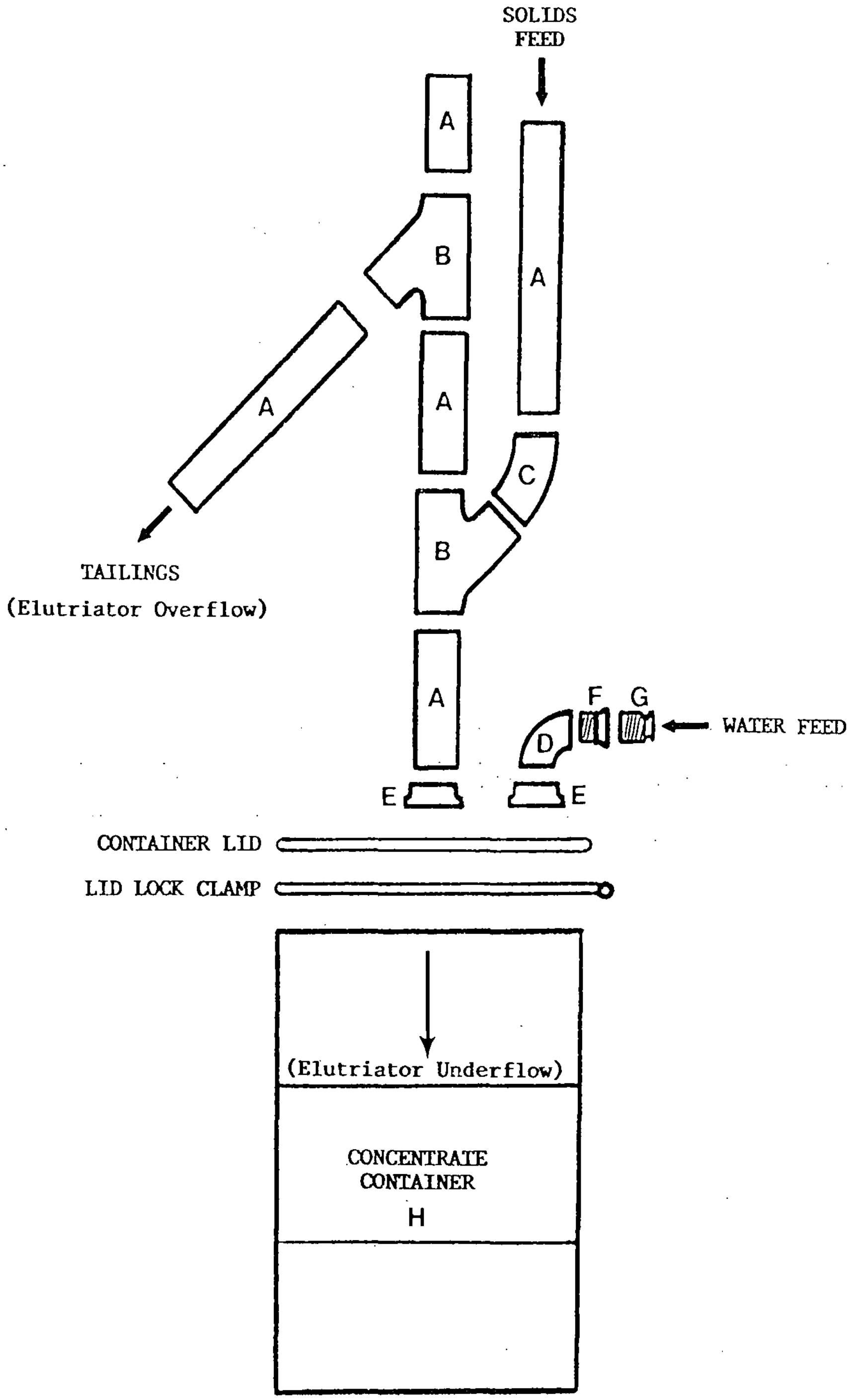


Figure 7. Parts schematic for MIRL elutriator. 1991 U.S. dollar costs for parts are shown in in table 14. Scale for 'A' pipe lengths is 3/4 inch = 1 foot.

Table 14. 1990 U.S. Dollar Prices for Elutriator Components by Pipe Size.

Item	Description	Nominal Inside Pipe Diameter (inches)				
		1	1.5	2	3	4
A	Sch 40 ABS (Black Plastic Pipe), $/ft	$0.65	0.80	1.10	2.20	3.25
B	45° WYE, ABS	3.25	3.59	3.79	8.60	11.90
C	45° Street Elbow, ABS	1.10	1.19	1.29	3.49	8.00
D	90° Street Elbow, Steel	2.49	5.19	-	-	-
	90° Street Elbow, ABS	-	-	1.59	5.59	11.79
E	Floor Flange, Steel	3.10	3.59	4.55	-	-
	Closet Flange, ABS	-	-	-	5.29	4.49
F	Bushing Reducer/Adapter, ABS	-	0.99	1.69	6.24	8.29
G	633F Kamlok Quick Coupling	4.15	5.60	7.05	15.75	29.00
H	Container 1) 5 gallon Plastic Bucket w/ Lid - $4.50 2) Open Top Poly Drum w/ Lid a) 15 gallon - $26.50 b) 30 gallon - $36.50 c) 55 gallon - $48.50 3) Open Top Steel Drum w/ Lid a) 8 gallon - $26.30 b) 20 gallon - $36.20 c) 55 gallon - $65.70					

Other: ABS Pipe Glue - $2.50/4 oz.
Fasteners (nut/bolt/washer assembly) - $.30/ea.

CASE STUDY

Placer gold mining operations near Tofty, Alaska also recover tin as cassiterite (SnO_2) in their sluice box concentrates. In the fall of 1989, Shoreham Resources Ltd's, Cache Creek Mine approached MIRL for assistance in "cleaning-up" their gold-cassiterite, sluice box concentrate. While the -1/4 inch concentrate could be upgraded by jigging and tabling, the 1-1/4 x 1/4 inch material posed more of a problem. Elutriation offered an inexpensive solution for separating the cassiterite from the waste rock.

The actual, average specific gravity of the cassiterite from the Cache Creek Mine was measured using the procedure in the appendix, page 39, and determined to be 5.5 versus 7.0 for pure cassiterite. The variation is due to inclusions of lighter silicate minerals in the coarse, predominantly cassiterite particles. This compositional variation is also seen from the assay values of coarse cassiterite particles from the Cache Creek Mine. Theoretically, the stoichiometric composition of cassiterite, SnO_2, is 79% tin. However analysis of the coarse, Cache Creek Mine cassiterite yields a value of 57% tin.

The shape of the cassiterite was not spherical as the calculation of settling velocity via Eq. 3 assumes. While some particles approach spherical shape, the majority of particles have an estimated CSF of 0.7. By contrast, the average specific gravity of the waste rock was determined to be 2.5 and its shape factor was estimated at 0.3-0.1.

Tables 2 and 12 can be utilized to show that a 1-1/4 inch piece of 2.5 specific gravity gangue with a CSF of 0.3 has a settling velocity of approximately:

$$\begin{aligned} V_t &= [3.64 + (4.46-3.64)/2]\text{ft/sec (Shape Correction Factor)} \\ &= 4.1 \text{ ft/sec } (0.5) \\ &= 2.0 \text{ ft/sec} \end{aligned}$$

If a 3 inch nominal diameter pipe is used, a flow rate of 44 gpm (Table 13) would be required to reject 1-1/4 x 1/4 inch gangue.

Tables 7, 8 and 12 show that 1/4" Tofty cassiterite with a 5.5 specific gravity and a 0.7 CSF should have a settling velocity of approximately:

$$\begin{aligned} V_t &= (2.99 + [3.34-2.99]/2) \text{ ft/sec (Shape Correction Factor)} \\ &= 3.2 \text{ ft/sec } (0.9) \\ &= 2.8 \text{ ft/sec} \end{aligned}$$

Since 2.8 ft/sec is greater than 2.0 ft/sec, a 44 gpm flow through a 3 inch nominal diameter pipe should effect the separation of cassiterite from gangue. In fact, flows above 44 gpm may improve separation efficiencies. The equivalent flow rate in a 3 inch pipe for a flow velocity of 2.8 ft/sec is approximately 62 gpm (Table 13). Based on these values, an elutriator was constructed from 3 inch ABS pipe as shown in Figure 6. Successful laboratory results led to field testing the elutriator at the Cache Creek Mine in September, 1990.

The mine's primary recovery system is shown in Figure 8. The run of mine ore is fed to a wash box, ahead of a double deck vibrating screen, at a rate of 80-90 yd^3/hr, by a Cat backhoe. The screen is fitted with a 1-1/4 inch top screen deck and a 1/4 inch lower screen deck. +1-1/4 inch material is discarded as coarse tailings. The 1-1/4 x 1/4 inch ore is treated in the far left sluice channel, while -1/4 inch material is divided and processed by the remaining two channels of the sluice box. Sluice tailings are removed from the lower end of the box by a front end loader, which also removes the +1-1/4 inch tailings. Fine material carried downstream by the sluicing water is captured and retained in a settling pond. The operation employs 100% recycle of all process water.

Shortly after the author arrived at the mine, the sluice box was temporarily shut down so that a sample could be taken from the 1-1/4 x 1/4 inch sluice channel. A four foot length of the sluice box was cleaned out near its feed end. This material was stored in buckets and later used for elutriator test runs. Size distributions of the cassiterite and waste rock of this sample are shown in Table 15. The majority of both waste rock and cassiterite lies in the 3/4 x 1/4 inch size fraction. Only 3-8% of the material taken from the 1-1/4 x 1/4 inch sluice channel was coarser than 3/4 inch. The feed grade of this material was approximately 26% tin or 46% cassiterite

The elutriator was set up next to the mine's cleanup shed, near a 1-1/2 inch water supply line pressurized by a 1 inch fresh water pump. This line had the capability of providing the elutriator with a maximum flow rate of 49 gpm (V_q = 2.1 ft/sec). The field setup of the elutriator is shown in Figure 9. Elutriator tailings were discharged onto a 5/32 inch screen so they could be visually inspected and recovered for subsequent analysis. The cassiterite concentrate was collected from the elutriator underflow in a bucket secured within the 55 gallon drum. Field test runs were conducted at flow rates of 49, 43, 38, and

Table 15. Size Distributions for the Coarse Cassiterite and Coarse Gangue of the Sluice Box Concentrate

Size Fraction (inches)	Cassiterite Wt %	Gangue Wt %
1-1/4 x 1	1.5	3.0
1 x 3/4	1.5	5.0
3/4 x 1/2	15.5	17.5
1/2 x 3/8	46.0	41.5
3/8 x 1/4	35.5	33.0
TOTAL	100.0	100.0

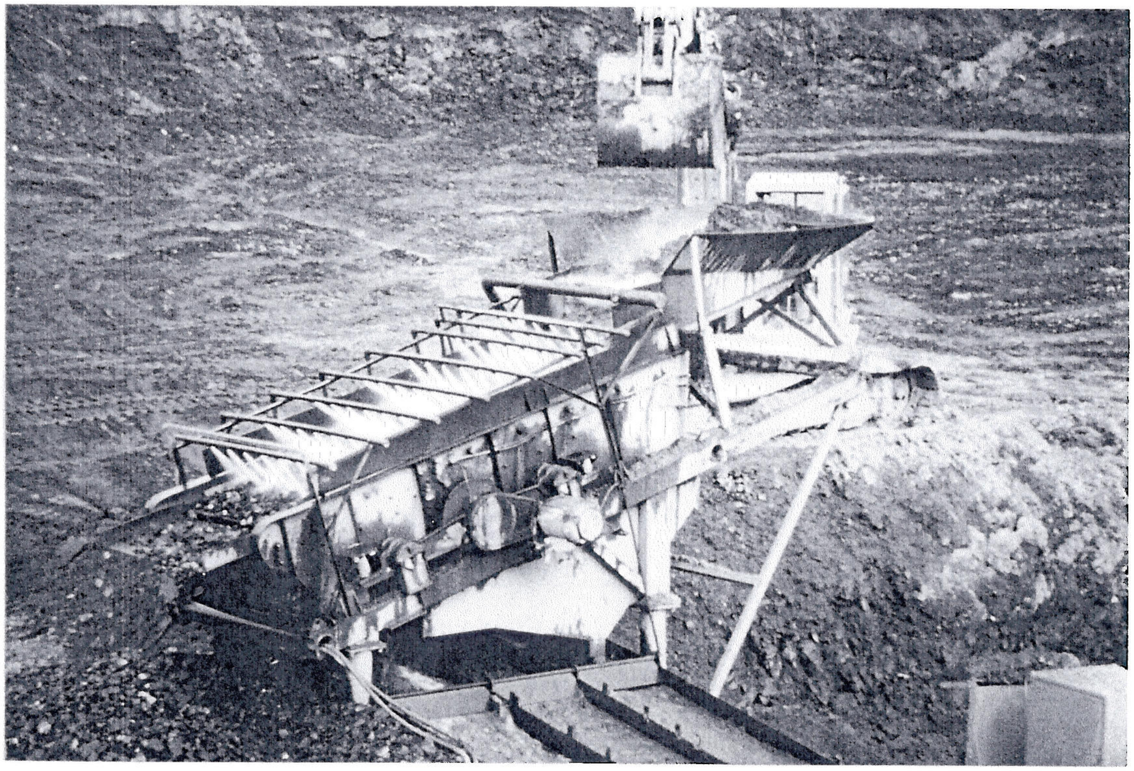


Figure 8. Shoreham Resources Ltd., Cache Creek Mine's primary recovery system for gold and cassiterite.

33 gpm; 2.1, 1.9, 1.7, and 1.4 ft/sec elutriator flow velocities respectively. Flow rates were determined using a doppler type flowmeter. During the field tests, the elutriator was manually fed material by the mine foreman. To perform a test, the system was operated by starting the water flow and adjusting it to give the desired flow rate through the sorting column of the elutriator as indicated by the flowmeter. Once the flow velocity was adjusted and stabilized, the sluice box concentrate was fed into the funnel atop the feed column of the elutriator. At the junction of the feed column and sorting column, the particles entered the water flow of the elutriator and were sorted according to their individual settling velocities. Material was fed to the elutriator manually from a scoop at a feed rate of approximately 10 lb/minute. Material (heavy concentrate) with a settling velocity sufficient to overcome the upward flow velocity of the water, passed down through the elutriator and was collected in a bucket within the 55 gallon drum. Material (light tailings) with a settling velocity less than the upward flow velocity of the water was carried up the sorting column and discharged from the elutriator through the downward sloping discharge pipe. Tailings fell onto a dewatering screen.

At the completion of each test run, the elutriator concentrate and tailings products were placed in separate plastic buckets and sealed for transport to MIRL where they were analyzed further. Particles from both products were sorted according to their composition, either cassiterite or waste. Any misplaced material, i.e. cassiterite in the tailings or waste rock in the concentrate, was then screened to determine which size fraction it fell into. Results were recorded.

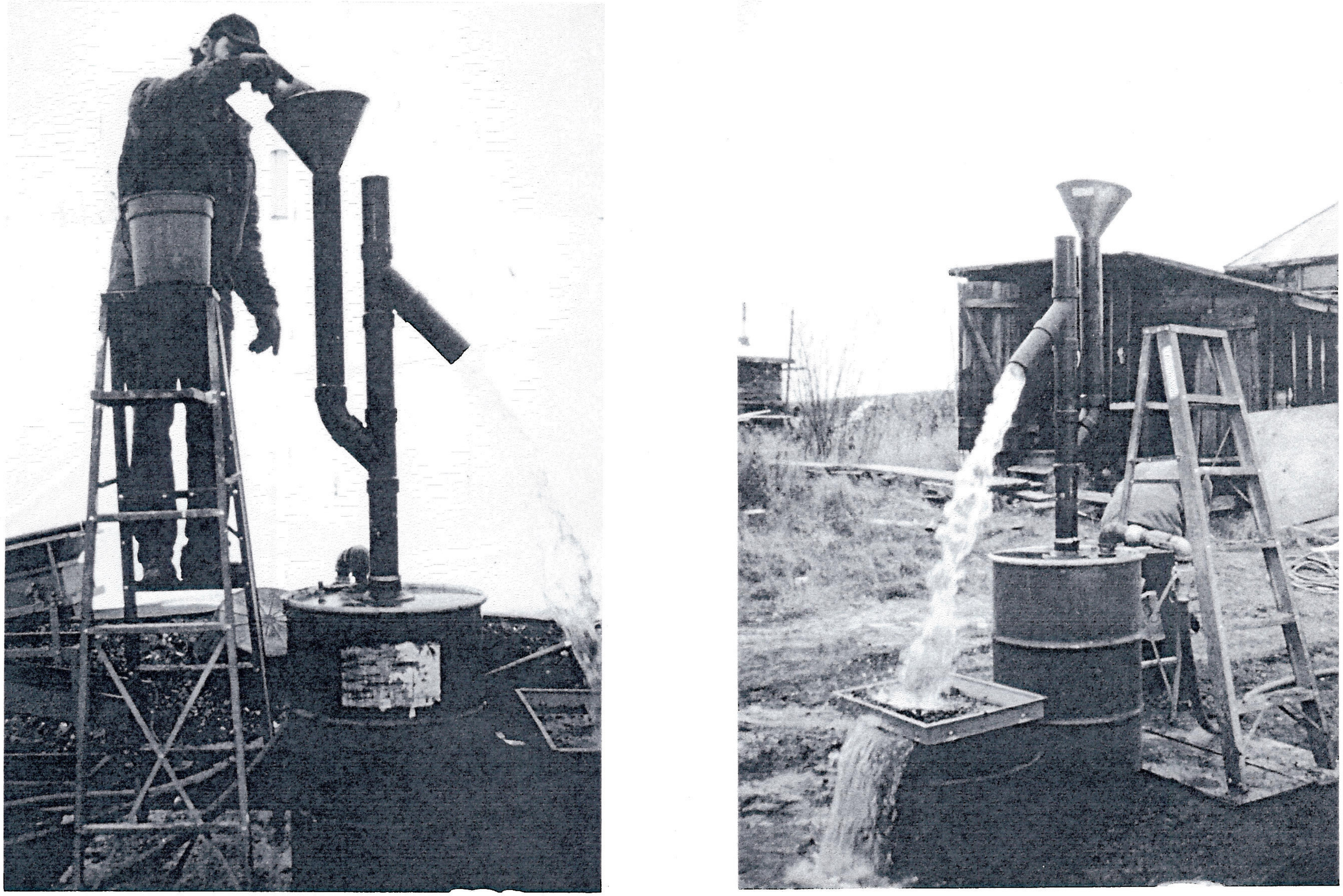
Cassiterite recovery and waste rock rejection efficiency data are shown in Tables A1 - A4 of the appendix and summarized in Figures 10 and 11. Operation at higher flow rates gave superior waste rock rejection at the expense of lower cassiterite recoveries in the finer size fractions. Operation at lower flow rates gave excellent recoveries of even fine size fraction cassiterite, but with poorer rejection of waste rock and the attendant dilution of cassiterite concentrate grade. This dependent, grade-recovery relationship is shown in Figure 12. Recovery of tin is maximized at a flow rate of 33 gpm and grade is maximized at approximately 43 gpm.

Cassiterite produced at the Cache Creek Mine was transported to Fairbanks using back-haul transportation, then shipped to Seattle via the Alaska Railroad (Fairbanks-Anchorage) and by barge (Anchorage-Seattle). The cost of this freighting was $0.16/lb. At Seattle, the cassiterite was received on consignment by Metal Markets Ltd. (MML) of North Humberside, England.* MML pays the New York dealers' tin price less $0.60/lb for the received cassiterite concentrate based on its refereed assayed tin value.

* Metal Markets Ltd./ The Louis Pearlman Center / Goulton St., Hull / N. Humberside, England / Fax: (0) 482-225-951 / Tel: (0) 482-225-940.

Based on the data from Tables A1-A4, a net profit index was computed for each field tests and these are presented in Table 16. This exercise demonstrates that the elutriator should be operated at least at a 49 gpm flow rate to achieve a cassiterite recovery of 98%, a tin grade of 56% and maximum profitability.

The elutriator proved to be a remarkably efficient and cost effective device for the application of separating the 1-1/4 x 1/4 inch cassiterite from the waste rock of the concentrate from the Cache Creek Mine sluice box. Besides its low cost, the elutriator is extremely simple to operate and adjust. A sample of 1/2 x 1/4 inch cassiterite can be fed to the elutriator and the flow rate adjusted to the point where this material is no longer rejected, as visually observed on a elutriators tailings screen. This flow rate setting should place the elutriator in a rather robust efficiency range of ± 5 gpm. Alternatively in a field setting, a water flow rate to the elutriator could be determined from timed, elutriator discharge water collection in a container of known volume. For example, at 43 gpm, the elutriator discharge water should fill a 55 gallon drum in 78 seconds.



(a) (b)

Figure 9. Field testing the elutriator at Cache Creek Mine, Tofty, Alaska. (a) Feeding the elutriator and (b) elutriator overflow discharging onto the tailings collection screen.

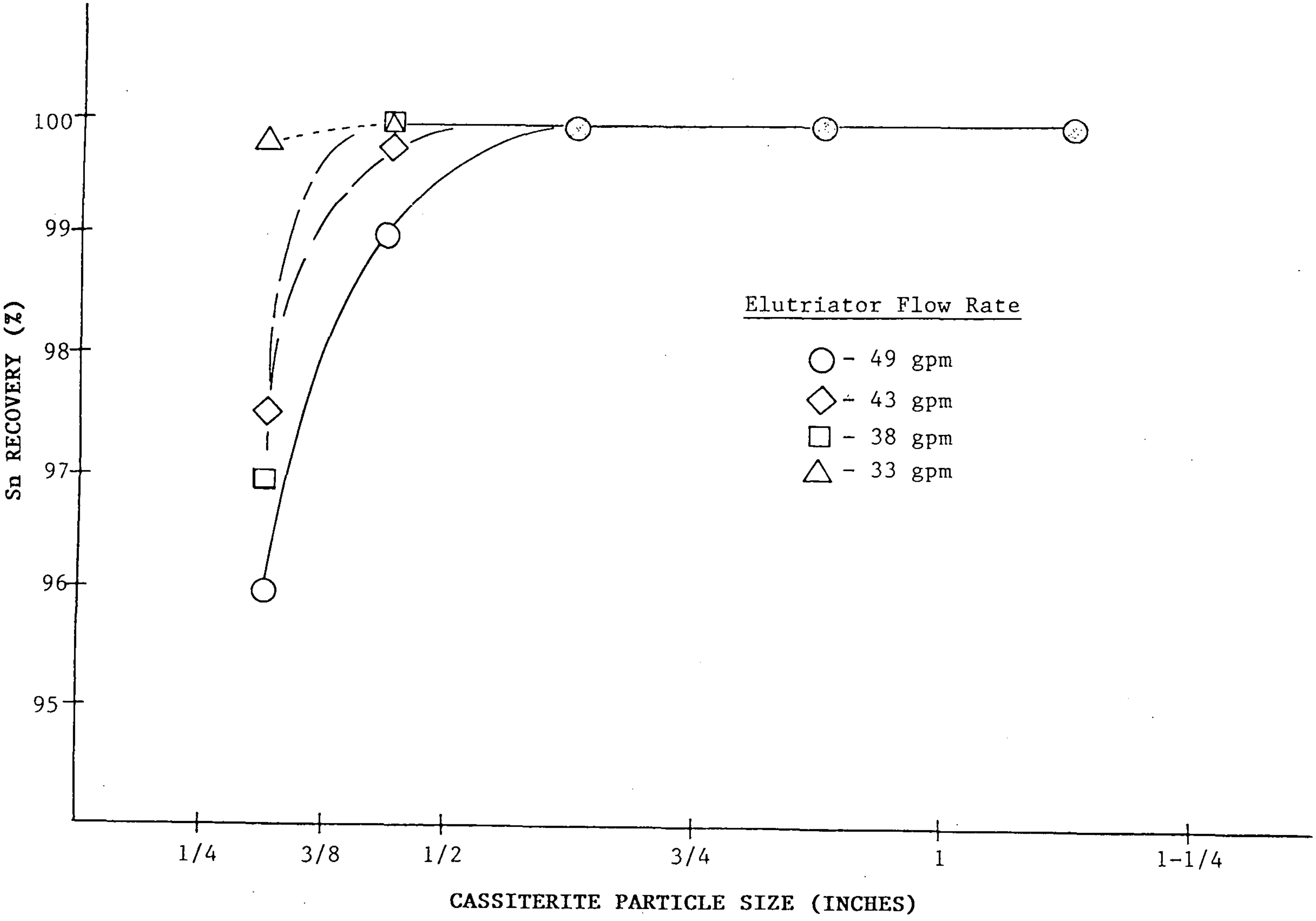


Figure 10. Cassiterite recovery as a function of particle size and elutriator flow rate.

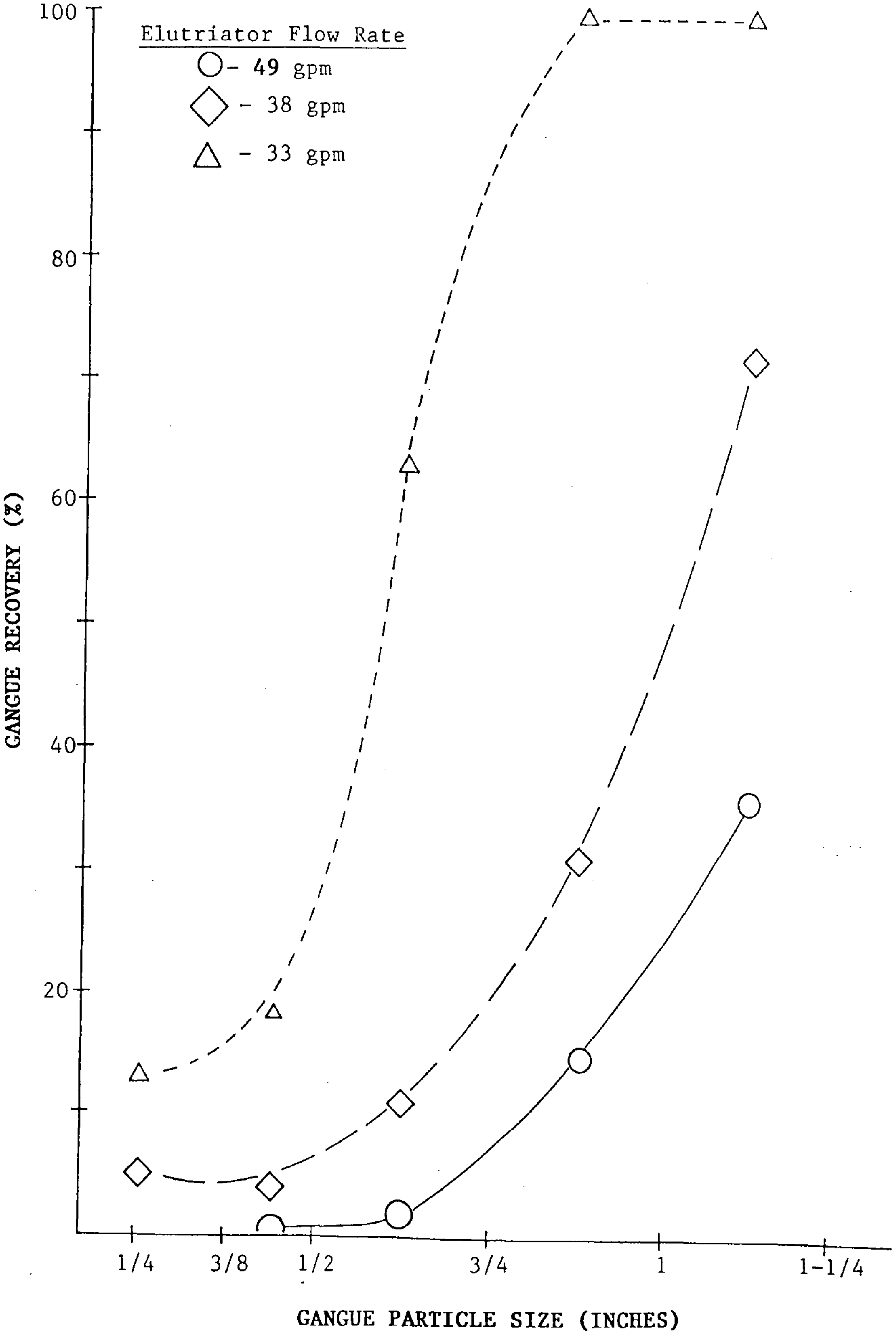


Figure 11. Gangue recovery as a function of particle size and elutriator flow rate.

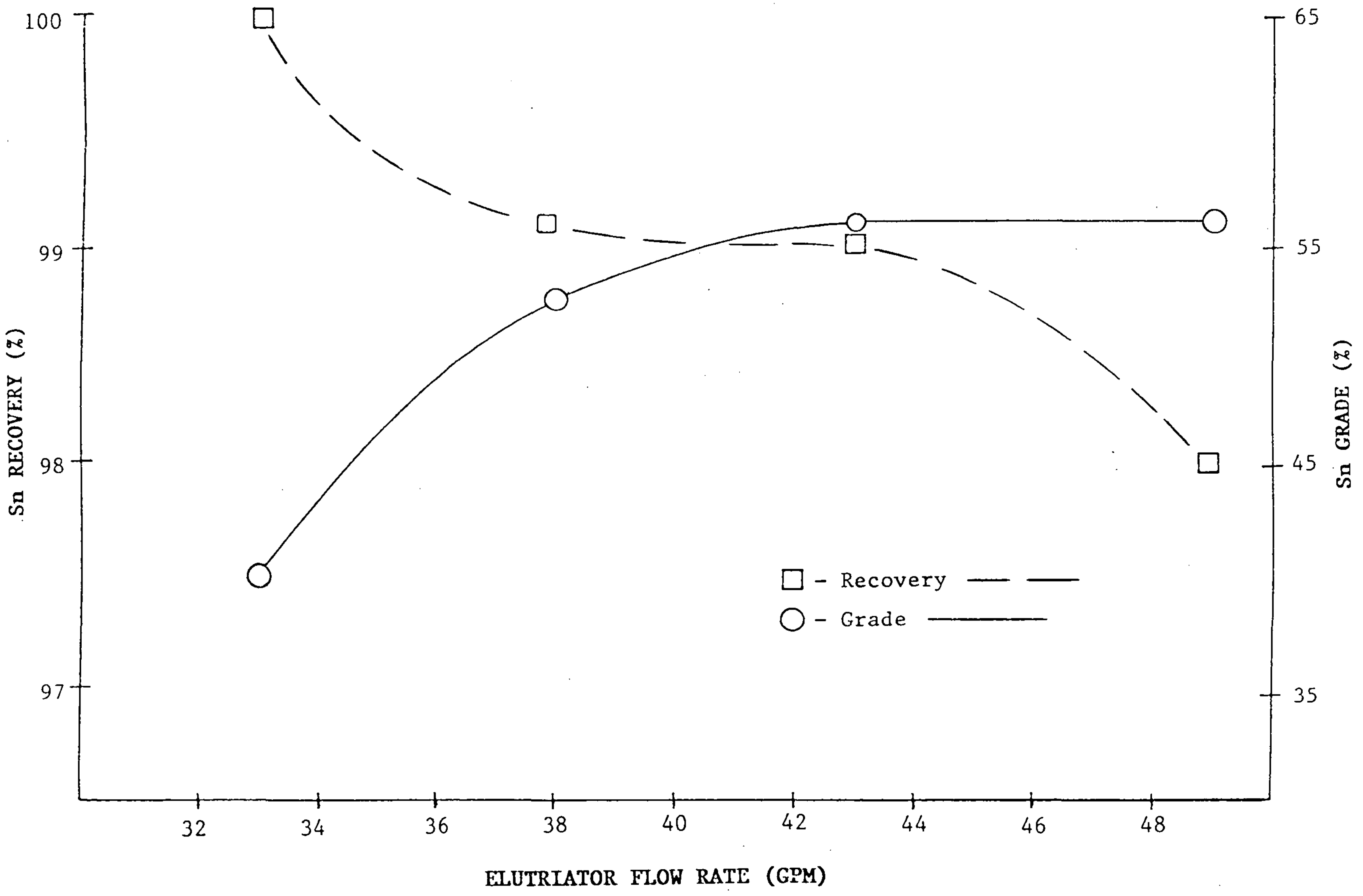


Figure 12. Cassiterite recovery and concentrate grade as a function of elutriator flow rate.

Table 16. Elutriator Performance Summary for Field Tests.

Field Test	Elutriator Flow Rate (gpm)	Concentrate Recoveries (%) Cassiterite	Concentrate Recoveries (%) Gangue	Tailings Recoveries (%) Cassiterite	Tailings Recoveries (%) Gangue	Net Profit per 100 lbs. feed to elutriator ($)*
1	49	98.08	1.44	1.92	98.56	52.34
2	43	99.01	7.88	0.99	92.12	52.28
3	38	99.14	8.33	0.86	91.67	52.31
4	33	99.92	35.50	0.08	64.50	50.38

* Defined as: $P=100\ (.46)\ (.57)\ R_C\ (\$2.80-\$0.60-\$0.16) - 100(.54)\ R_G\ (\$0.16)$

$= R_C\ (\$53.49) - R_G\ (\$8.64)$

where: R_C = Recovery of cassiterite in concentrate

R_G = Recovery of gangue in concentrate

This assumes:
1) Feed to elutriator grades 46% cassiterite
2) Cassiterite grades 57% tin metal
3) NY Dealer tin price of $2.80/lb
4) $0.60/lb smelting charge
5) $0.16/lb freight charge

SUMMARY

This manual addresses the design and fabrication of an elutriation system for the separation of coarse heavy minerals from waste rock. Elutriation is a process for separating a mixture of minerals into two or more products and utilizes the difference in settling velocity between particles to effect this separation. An upward flow of water runs countercurrent to the material flow in a hollow elutriation column. Particle separation is affected by particle density, size and shape and the upward water velocity.

Elutriation provides an inexpensive method for processing +1/4 inch, sluice box concentrate to recover by-product heavies. Elutriator design emphasizes the use of materials which are inexpensive and readily available to the average placer gold mining company. The design also incorporates concentrate storage and shipment functionality into a detachable section of the elutriator.

This manual includes a number of tables to aid in the design of an elutriator. Component cost data for elutriator construction is also included in tabular form. An example of elutriator design for a specific application is also included as well as performance data for that application.

Design is based on the construction of a prototype unit and testing of the unit for coarse cassiterite (SnO_2) recovery efficiency. Field testing utilized 1-1/4" x 1/4" sluice box concentrate from Shoreham Resources Ltd's Cache Creek Mine, Tofty, Alaska. Field testing was highly successful. The elutriator proved to be a simple, robust concentrator for this application and produced tin recoveries and grades in excess of 99% and 55% respectively. Field feed grades to the elutriation unit were approximately 26% tin.

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APPENDIX

SETTLING VELOCITY SUMMARY SHEET

Reynolds Number: $Re = \frac{V_t d \rho_l}{\mu}$

Stokes' Law: $V_t = \frac{g(\rho_s - \rho_l)d^2}{18\mu}$ $Re \leq 1$ (Laminar flow)

Newton's Law: $V_t = \left[\frac{3.33\ g(\rho_s - \rho_l)d}{\rho_l}\right]^{1/2}$ $Re \geq 1000$ (Turbulent flow)

Transitional: $V_t = \left[\frac{4g(\rho_s - \rho_l)d}{3\ C_D \rho_l}\right]^{1/2}$ $1 < Re < 1000$ (Transitional flow)

From $V_{ta} = V_{tb}$ we derive free settling ratios:

Free Settling Ratio: $\frac{d_a}{d_b} = \left(\frac{\rho_b - \rho_l}{\rho_a - \rho_l}\right)$ (Newtonian)

Free Settling Ratio: $\frac{d_a}{d_b} = \left(\frac{\rho_b - \rho_l}{\rho_a - \rho_l}\right)^{1/2}$ (Stokes)

General Considerations:

1. If two particles have the same density, then the particle with the larger spherical diameter has the higher settling velocity.
2. If two particles have the same spherical diameter, then the denser particle has the higher settling velocity.
3. If two particles have the same density and diameter, then the particle with the higher Corey shape factor has the higher settling velocity.
4. Stoke's Law applies to spherical quartz particles less than 125 microns in size, cassiterite particles less than 70 microns in size and gold particles less than 53 microns in size.
5. Newton's Law applies to spherical quartz particles greater than 3 mm in size, cassiterite particles greater than 2 mm in size and gold grains greater than 1.5 mm in size.

DENSITY DETERMINATION WORKSHEET

1) Obtain an adequate size container whose volume (V) is accurately known in milliliters (cm^3).
2) Weigh the empty, dry container: ________ grams (W_0)
3) Add the mineral sample to the container and reweigh: ________ grams (W_1)
4) Fill the container holding the sample to the known volume level with water and reweigh: ________ grams (W_2)
5) Perform the following computations:
Volume of solids (Vs) = $V - (W_2 - W_1)$ = ____________ cm^3
Average specific gravity of solids = $(W_1 - W_0) / V_S$ = ____________ grams / cm^3

Table A1. Elutriator Performance Data for Field Test No. 1.

Elutriator Flow Rate: 49 gpm
Elutriator Flow Velocity: 2.1 ft/sec.

Particle Size Fraction (inches)	ELUTRIATOR CONCENTRATE Fractional mass (g)	Cassiterite mass (g)	Cassiterite # particles	Gangue mass (g)	Gangue # particles	Grade % Sn	Sn Recovery %
1.25 x 1.00	208.2	156.0	3	52.2	1	43	100
1.00 x 0.75	34.8	34.8	1	0.0	0	57	100
0.75 x 0.50	844.7	826.2	70	18.5	3	56	100
0.50 x 0.38	2319.3	2298.8	>100	20.5	6	56	99
0.38 x 0.25	2174.0	2171.8	>100	2.2	3	57	96
Concentrate Subtotal	5581.0	5487.6	--	93.4	13	56	98

Particle Size Fraction (inches)	ELUTRIATOR TAILINGS Fractional mass (g)	Cassiterite mass (g)	Cassiterite # particles	Gangue mass (g)	Gangue # particles	Grade % Sn	Sn Recovery %
1.25 x 1.00	94.3	0.0	0	94.3	2	-	0
1.00 x 0.75	246.6	0.0	0	246.6	2	-	0
0.75 x 0.50	1191.8	0.0	0	1191.8	>100	-	0
0.50 x 0.38	2732.3	22.8	10	2709.5	>100	-	1
0.38 x 0.25	2222.4	84.8	70	2137.6	>100	-	4
Tailings Subtotal	6487.5	107.6	80	6379.8	-	0.94	2

Particle Size Fraction (inches)	RECONSTITUTED ELUTRIATOR FEED Mass (g)	Mass Cassiterite (g)	Mass Gangue (g)	Grade (% Sn)
1.25 x 0.25	12,068.5	5595.2	6473.2	26

Concentration Ratio: 2.16
(mass feed/mass concentrate)

Table A2. Elutriator Performance Data for Field Test No. 2.

Elutriator Flow Rate: 43 gpm
Elutriator Flow Velocity: 1.9 ft/sec.

	ELUTRIATOR CONCENTRATE						Sn
Particle Size	Fractional	Cassiterite		Gangue		Grade	Recovery
Fraction (inches)	mass (g)	mass (g)	# particles	mass (g)	# particles	% Sn	%
1.25 x 1.00	74.5	74.5	1	0.0	0	57	100
1.00 x 0.75	120.2	61.9	2	58.3	4	29	100
0.75 x 0.50	654.8	648.6	70	6.2	2	56	100
0.50 x 0.38	2373.4	2368.3	>100	5.1	3	57	100
0.38 x 0.25	1514.0	1484.3	>100	29.7	27	56	97
Concentrate Subtotal	4736.9	4637.6	-	99.3	36	56	99

	ELUTRIATOR TAILINGS						Sn
Particle Size	Fractional	Cassiterite		Gangue		Grade	Recovery
Fraction (inches)	mass (g)	mass (g)	# particles	mass (g)	# particles	% Sn	%
1.25 x 1.00	104.0	0.0	0	104.0	3	-	0
1.00 x 0.75	301.1	0.0	0	301.1	25	-	0
0.75 x 0.50	1045.3	0.0	0	1045.3	>100	-	0
0.50 x 0.38	2425.0	0.0	0	2425.0	>100	-	0
0.38 x 0.25	1902.1	46.5	39	1855.6	>100	-	3
Tailings Subtotal	5777.5	46.5	39	5731.0	-	0.4	1

	RECONSTITUTED ELUTRIATOR FEED			
Particle Size Fraction (inches)	Mass (g)	Mass Cassiterite (g)	Mass Gangue (g)	Grade (% Sn)
1.25 x 0.25	10,514.4	4684.1	4830.3	25

Concentration Ratio: 2.22
(mass feed/mass concentrate)

Table A3. Elutriator Performance Data for Field Test No. 3.

Elutriator Flow Rate: 38 gpm
Elutriator Flow Velocity: 1.7 ft/sec.

Particle Size Fraction (inches)	ELUTRIATOR CONCENTRATE Fractional mass (g)	Cassiterite mass (g)	Cassiterite # particles	Gangue mass (g)	Gangue # particles	Grade % Sn	Sn Recovery %
1.25 x 1.00	68.0	0.0	0	68.0	1	0	-
1.00 x 0.75	93.2	58.8	2	34.4	2	36	100
0.75 x 0.50	660.4	599.4	50	61.0	12	52	100
0.50 x 0.38	1591.8	1528.9	>100	62.9	34	55	99.8
0.38 x 0.25	1104.7	1043.3	>100	61.4	74	54	97.6
Concentrate Subtotal	3518.1	3230.4	-	287.7	123	52	99.1

Particle Size Fraction (inches)	ELUTRIATOR TAILINGS Fractional mass (g)	Cassiterite mass (g)	Cassiterite # particles	Gangue mass (g)	Gangue # particles	Grade % Sn	Sn Recovery %
1.25 x 1.00	25.1	0.0	0	25.1	1	0	-
1.00 x 0.75	78.0	010	0	78.0	6	0	0
0.75 x 0.50	507.3	0.0	0	507.3	97	0	0
0.50 x 0.38	1322.9	2.5	1	1320.4	>100	0.1	0.2
0.38 x 0.25	1259.5	25.4	21	1234.1	>100	1.1	2.4
Tailings Subtotal	3192.8	27.9	22	3164.9	-	0.5	0.9

Particle Size Fraction (inches)	RECONSTITUTED ELUTRIATOR FEED Mass (g)	Mass Cassiterite (g)	Mass Gangue (g)	Grade (% Sn)
1.25 x 0.25	6710.9	3258.3	3452.6	28

Concentration Ratio: 1.91
(mass feed/mass concentrate)

Table A4. Elutriator Performance Data for Field Test No. 4.

Elutriator Flow Rate: 33 gpm
Elutriator Flow Velocity: 1.4 ft/sec.

Particle Size Fraction (inches)	ELUTRIATOR CONCENTRATE Fractional mass (g)	Cassiterite mass (g)	Cassiterite # particles	Gangue mass (g)	Gangue # particles	Grade % Sn	Sn Recovery %
1.25 x 1.00	268.4	0.0	0	268.4	8	0	100
1.00 x 0.75	354.3	98.3	3	256.0	18	16	100
0.75 x 0.50	807.9	470.9	40	337.0	67	33	100
0.50 x 0.38	1639.7	1363.7	>100	276.0	>100	47	100
0.38 x 0.25	1170.4	1035.0	>100	135.4	99	50	99.8
Concentrate Subtotal	4240.7	2967.9	-	1272.8	-	40	99.9

Particle Size Fraction (inches)	ELUTRIATOR TAILINGS Fractional mass (g)	Cassiterite mass (g)	Cassiterite # particles	Gangue mass (g)	Gangue # particles	Grade % Sn	Sn Recovery %
1.25 x 1.00	0.0	0.0	0	0.0	0	-	0
1.00 x 0.75	0.0	0.0	0	0.0	0	-	0
0.75 x 0.50	199.7	0.0	0	199.7	59	-	0
0.50 x 0.38	1214.3	0.0	0	1214.3	>100	-	0
0.38 x 0.25	900.8	2.5	2	898.3	>100	-	0.2
Tailings Subtotal	2314.8	2.5	2	2312.3	-	0.06	0.1

Particle Size Fraction (inches)	RECONSTITUTED ELUTRIATOR FEED Mass (g)	Mass Cassiterite (g)	Mass Gangue (g)	Grade (% Sn)
1.25 x 0.25	6555.5	2970.4	3585.1	26

Concentration Ratio: 1.55
(mass feed/mass concentrate)