Article

Laboratory-Scale Optimization of Celestine Concentration Using a Hydrocyclone System

Noemi Ariza-Rodríguez, Alejandro B. Rodríguez-Navarro, Mónica Calero de Hoces and Mario J. Muñoz-Batista

SUPPLEMENTARY INFORMATION

The previous mineral conditioning was made in Canteras Industriales S.L. and Advanced Mineral Processing facilities. **Figure S1** shows the conditioning and delamination equipment.

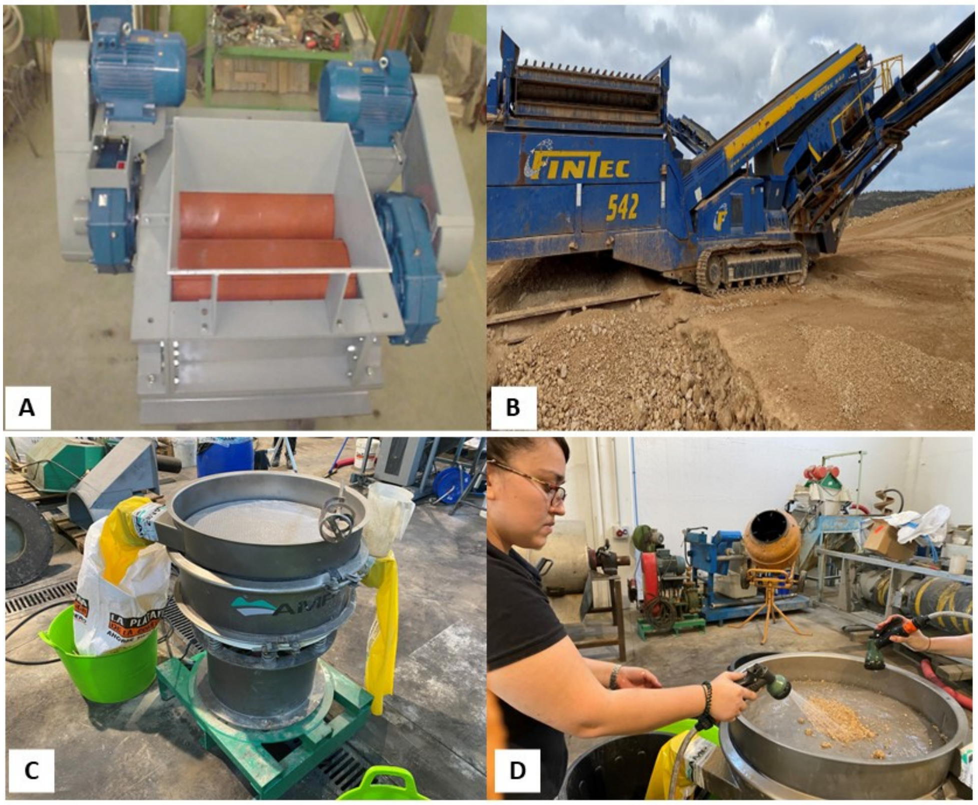

Figure S1. Conditioning.

Table S1, S2 show data related to the characteristics of FeSi (ferrosilicon) applied in the tests. Table S3 the particle size distribution of atomized FeSi. Table S4 shows the elemental content of the magnetite used in the dense FM medium (2:1 FeSi:Magnetite). Table S4 and Table S5 lists the particle size of magnetite.

Table S1. Interest elements content in FeSi *(Source: Acomet)*.

Chemical Elements	Content% in weight
Si	75 % min
Al	0.75 – 1.20 %
C	0.1 % max
P	0.05 % max
S	0.015 % max

Table S2. Physical properties of FeSi (Source: Acomet).

Physical properties	Value
Density	Density > 7.000 kg/m^3 (typical value 7.420 kg/m^3)
Non-magnetic	< 0,50 % (typical value 0,13 %)
Susceptibility Magnetic	> 58 % (typical value 69 %)

Table S3. Size particle Atomised FeSi.

% < 45 µm FeSi 14/16 **Atomised**:	
Coarse Grade	32 -- 40
Fine Grade	42 -- 50
Cyclone 40	82 - -90

(Source: Acomet)

Table S4. Elements content in Magnetite (Source: Acomet).

	Content% in weight
Total Fe	> 60 %.
Total Fe_3O_4	> 85
SiO_2	< 1.50 % SiO_2 < 1.50 % Al_2O_3 < 1.50 % Al_2O_3 < 1.50
Al_2O_3	< 1.50 % Al_2O_3 < 1.50
CaO	< 0.20
MnO	< 0.25
AFS	size 90 +/-2

Table S5. Size particle magnetite DMS80.

Magnetite (DMS80)	
Mesh	Retained (%)
200 µm	<5
270 µm	<10
325 µm	<22
<325 µm	80-86

Figure S2 shows images of the stability tests and Table S5 summarizes the stability and viscosity data obtained for each dense medium applied.

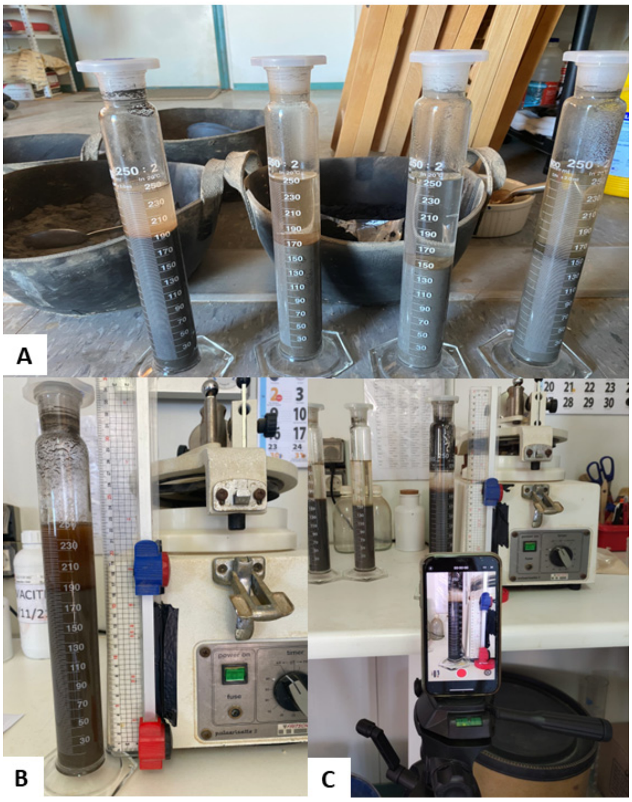

Figure S2. Stability test plot.

Table S6. Viscosity and stability of dense mediums applied.

	Visco	Stability
CG-SD	0.0928	-0.52
CG-D	0.0928	-0.52
C40-SD	0.0932	-0.13
C40-D	0.0932	-0.13
FINE-SD	0.0049	-0.42
FINE-D	0.0049	-0.42
FINE66-SD	0.0969	-0.09
FINE66D	0.0969	-0.09

Figure S3 details both the lower and upper crankcase assemblies. Also shown in the 75 mm diameter hydrocyclone model (HYDROCYCLONE AMP HYDROVORTEX® PP PP007081).

SUMP CHARACTERISTICS

It has rectangular section and manufactured in stainless steel; it is screwed to the supporting structure. It has specific brackets to attach the hydrocyclone fasteners structures. The sump has two parts: lower sump, the pump takes the feeding pulp from there; and the upper sump, which is divided in two, to separate Underflow and Overflow coming from the hydrocyclones. Both upper sumps, have manual handling discharge valves, that allows the recirculating of one or both products to the feeding sump (lower sump).

SUPPORTING STRUCTURE AND BASE: they are manufactured in structural steel tubes (S275JR), and placed over four wheels, two directional fixed and braked wheels and two steerable wheels.

HYDROCYCLONE CHARACTERISTICS

FRAME: manufactured in polyurethane, which provides high abrasion and chemical compounds resistance.

PARTS/COMPONENTS: The modular construction of these hydrocyclones, facilitates component interchangeability, which are fastened with flanges. The feed slurry enters the cylindrical section tangentially, causing it to swirl around the longitudinal axis of the hydrocyclone.

ADJUSTMENT COMPONENTS: Feeding nozzles, overflow and underflow nozzles with different diameter to get the required work conditions.

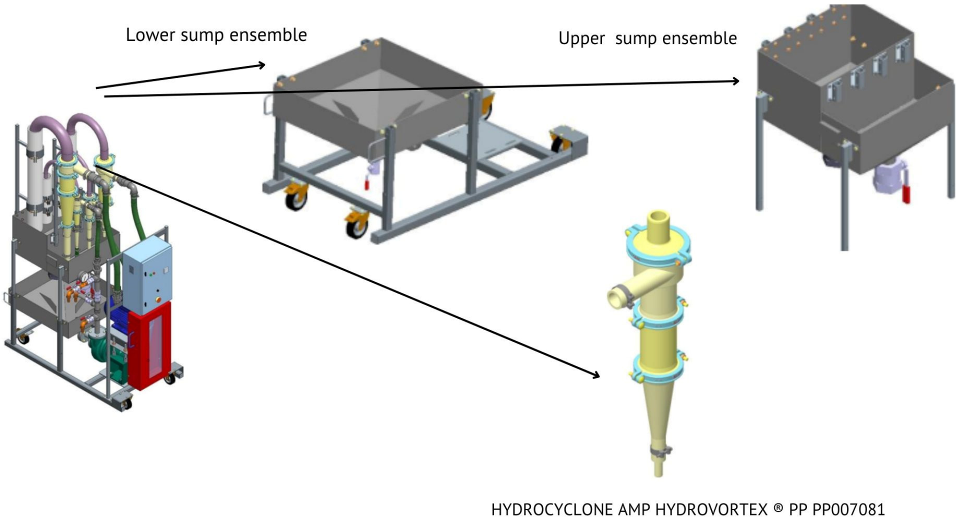

Figure S3. Schedule of AMP test equipment.

Figure S4 consists of actual images of the hydrocyclone plant. **Figure S4A** is a side view of the plant showing the pump-engine ensamble (centrifugal pum 2/1.5 B-MAR, electric engine 7.5 kW). Figure S4B shows the electric control cabinet (Metalic cabinet where the plant work parameters can be controlled, such as start/stop switch and pump speed controler. These parameters allow to adjust the pumping flow and pressure to get the most suitable work conditions with the hydrocyclone used). **Figure S4C** shows an actual image of the applied hydrocyclone.

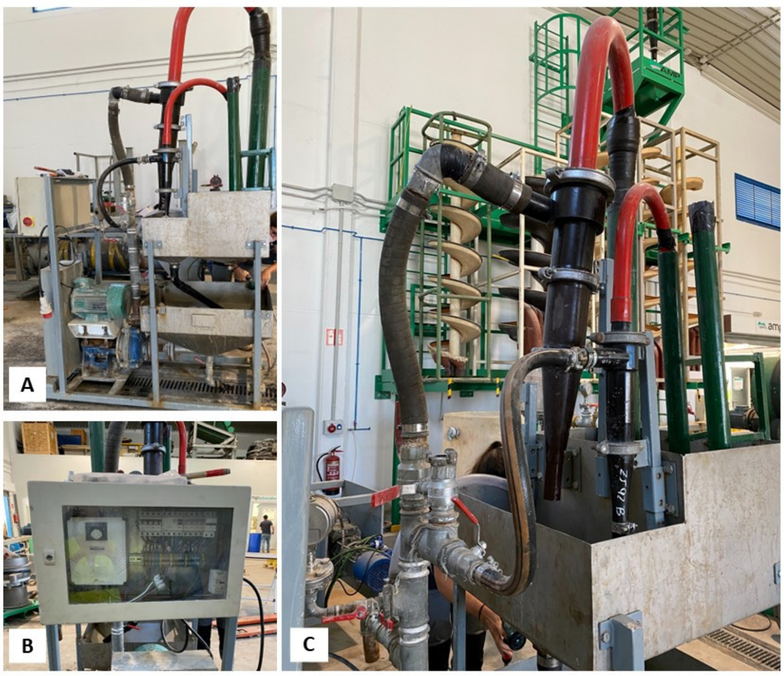

Figure S4. AMP Test equipment.

Figure S5AB corresponds to the magnetic separation equipment. **Figure S5C** is the flocculant used. An organic flocculant (MG) consisting of a mixture of surfactants in an acid medium was applied. It works on the highly diluted stream of the mineral stream obtained after magnetic separation, resulting in its agglomeration until a sufficient floc size is achieved, which after drying can be analysed by EDX. The product was added directly to the water.

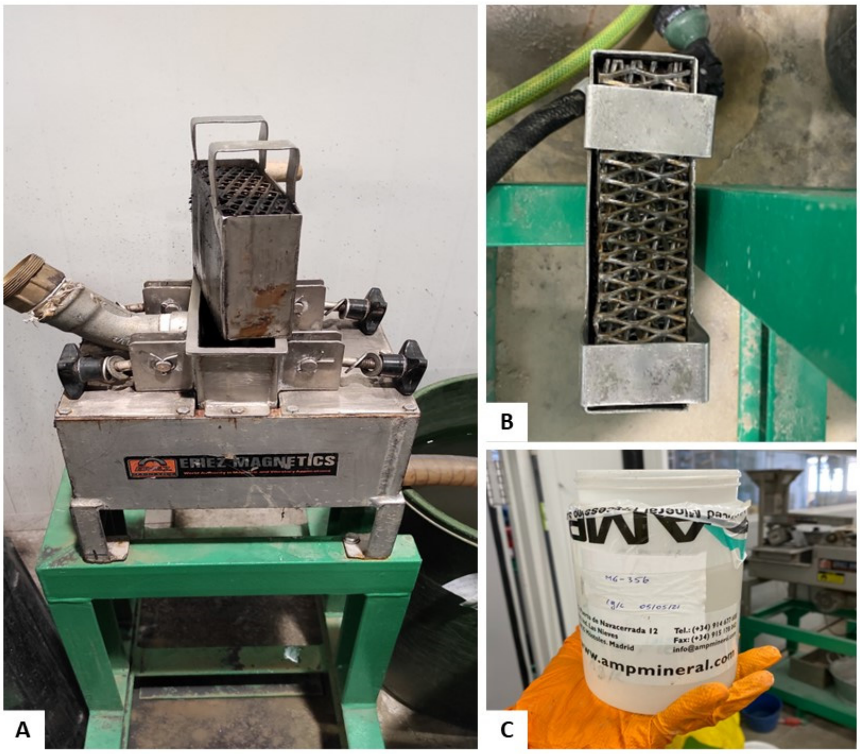

Figure S5. Magnetic separator.

Preliminary tests

TEST A:

The heavy mineral applied was CG with raw mineral without desliming. 35 liters water were put into the sump tank. Heavy mineral was added until the density of pulp was stabilised at 3000g/l. The hydrocyclone feeding pressure was fixed in 0.7 bar and researchers increased progressively this pressure to adequate it to the normal running of the hydrocyclone.

Finally, 20 kg mineral was put into the tank. Researchers observed that the level into the tank was over the optimum volume of processing.

TEST B:

The heavy mineral applied was CG with raw mineral without desliming. 35 liters water were put into the sump tank. Heavy mineral was added until the density of pulp was stabilised at 3 kg/l. The pressure was fixed in 0.7 bar and a sedimentation and segregation processes were detected at the bottom of the tank. The pressure was increase up to 1 bar to prevent solids sedimentation and avoid hydrocyclone blockage.

Finally, 10 kg mineral was put into the tank. Researchers observed that the level into the tank and the pressure were optimum to carry out the test based on operational and rheological criteria.

An ore piece larger than 6 mm causes a clogging failure in the hydrocyclone body (tangential feedeing nozzle) after the sink and float samples were taken.

For these reasons, the researchers decided to operate with the following guidelines:

- -The addition of ore would be done when the density of the heavy medium (heavy ore + water) was 3 kg/l.
- -The pressure was set at 1 bar.
- -The amount of material was set at 10 kg.
- -The ore was sieved (#6mm) to avoid pieces of particles size larger over than 6 mm.

Table S7 shows the theoretically calculated FeSi and magnetic masses for each test, as well as the empirical weights obtained.

Table S7. Theorical and empirical weights.

Nº	Heavy mineral	Mass Water (Kg)	Theorical mass FeSi (Kg)	Theorical mass Magnetite (Kg)	Empirical mass FeSi (Kg)	Empirical mass Magnetite (Kg)
1	CG_	35.8	119.2	0.00	43.75	
2	CG_D	35.8	119.2	0.00	63.35	
3	C40_	35.8	119.2	0.00	78.05	
4	C40_D	35.8	119.2	0.00	95.55	
5	F_	35.1	119.2	0.00	60.30	
6	F_D	35.8	119.2	0.00	86.05	
7	FM_	33.2	80.4	41.4	71.05	36.6
8	FM_D	33.2	80.4	41.4	66.76	34.4

Table S8 shows the total mass of ore after the concentration process in each stream OU250, OO250, UU250 and UO250 for each dense medium.

Table S8. Obtained mass of each stream.

Heavy mineral	output	% OF TOTAL	mass (Kg)
CG	1 OU250	0.21	2.08
	1 OO250	0.00	0.02
	1 UU250	0.21	2.14
	1 UO250	0.58	5.76
C40	3 OU250	0.64	6.35
	3 OO250	0.15	1.50
	3 UU250	0.07	0.72
	3 UO250	0.14	1.43
FINE	5 OU250	0.04	0.37
	5 OO250	0.28	2.78
	5 UU250	0.05	0.48
	5 UO250	0.64	6.37

FM	7 OU250	0.06	0.60
	7 OO250	0.27	2.70
	7 UU250	0.10	0.98
	7 UO250	0.57	5.72
CG_D	2 OU250	0.01	0.11
	2 OO250	0.54	5.42
	2 UU250	0.02	0.16
	2 UO250	0.43	4.31
C40_D	4 OU250	0.01	0.05
	4 OO250	0.50	4.99
	4 UU250	0.08	0.84
	4 UO250	0.41	4.12
FINE_D	6 OU250	0.46	4.55
	6 OO250	0.23	2.33
	6 UU250	0.12	1.16
	6 UO250	0.20	1.96
FM_D	8 OU250	0.00	0.03
	8 OO250	0.36	3.58
	8 UU250	0.00	0.02
	8 UO250	0.64	6.37

Table S9 shows for each test and stream, the mineral phases present analyzed by XRD.

Table S9. XRD analysis and flow rate of output streams.

				DRX analysis						
Heavy Mineral	output	¿Desliming?	mass (kg)	**Celestine %**	**Stroncianite %**	**Quartz %**	**Dolomite %**	**Calcite %**	**Illite %**	**Total**
CG	1 OH	NO	2.08	39.09	1.69	7.95	14.27	35.5	1.5	100
	1 OL	NO	0.02	44.63	2.18	2.17	17.86	32.6	0.56	100
	1 UL	NO	2.14	72.47	1.22	9.01	5.73	9.9	1.65	100
	1 UH	NO	5.76	**81.05**	1.66	3.57	4.33	8.63	0.77	100
C40	3 OH	NO	6.35	63.51	2.87	7.47	8.85	15.53	1.72	100
	3 OL	NO	1.50	64.67	2.25	3.51	10.58	18.21	0.77	100
	3 UL	NO	0.72	66.36	2.87	6.98	7.36	14.98	1.44	100
	3 UH	NO	1.43	**89.75**	0.61	2.98	2.08	3.83	0.75	100
FINE	5 OH	NO	0.37	52.70	3.42	7.73	13.32	20.99	1.84	100
	5 OL	NO	2.78	47.96	1.6	2.73	14.9	32.17	0.64	100
	5 UL	NO	0.48	54.97	3.77	9.33	9.97	19.55	2.40	100
	5 UH	NO	6.37	**84.16**	1.34	2.45	4.01	7.39	0.64	100
FM	7 OH	NO	0.60	63.51	2.87	7.47	8.85	15.53	1.72	100
	7 OL	NO	2.70	47.67	2.25	3.51	10.58	35.21	0.77	100

	7 UL	NO	0.98	66.36	2.87	6.98	7.36	14.98	1.44	100
	7 UH	NO	5.72	**85.05**	0.61	3.98	5.08	4.53	0.75	100
CG_	2 OH	YES	0.11	61.28	6.64	7.46	9.72	11.53	3.38	100
	2 OL	YES	5.42	65.92	1.11	2.08	10.28	20.04	0.57	100
	2 UL	YES	0.16	57.64	4.02	5.69	11.67	18.21	2.72	100
	2 UH	YES	4.31	**81.87**	1.06	2.26	5.20	9.06	0.56	100
C40_	4 OH	YES	0.05	74.00	1.25	3.09	8.96	12.19	0.51	100
	4 OL	YES	4.99	46.98	2.65	9.5	15.50	24.38	0.98	100
	4 UL	YES	0.84	49.80	2.4	8.9	15.14	22.85	0.90	100
	4 UH	YES	4.12	**93.07**	1.06	1.64	1.08	2.55	0.60	100
FINE_	6 OH	YES	4.55	71.31	5.19	9.24	6.10	7.2	0.98	100
	6 OL	YES	2.33	46.36	1.49	2.59	18.3	30.55	0.72	100
	6 UL	YES	1.16	50.92	11.00	3.69	10.08	22.39	1.92	100
	6 UH	YES	1.96	**86.40**	0.70	3.01	2.76	6.95	0.18	100
FM_	8 OH	YES	0.03	60.55	1.33	2.15	13.55	21.88	0.55	100
	8 OL	YES	3.58	41.12	8.04	15.34	12.37	21.6	1.53	100
	8 UL	YES	0.02	31.53	7.79	19.51	15.14	24.31	1.72	100
	8 UH	YES	6.37	**85.43**	0.69	2.2	3.55	7.71	0.42	100

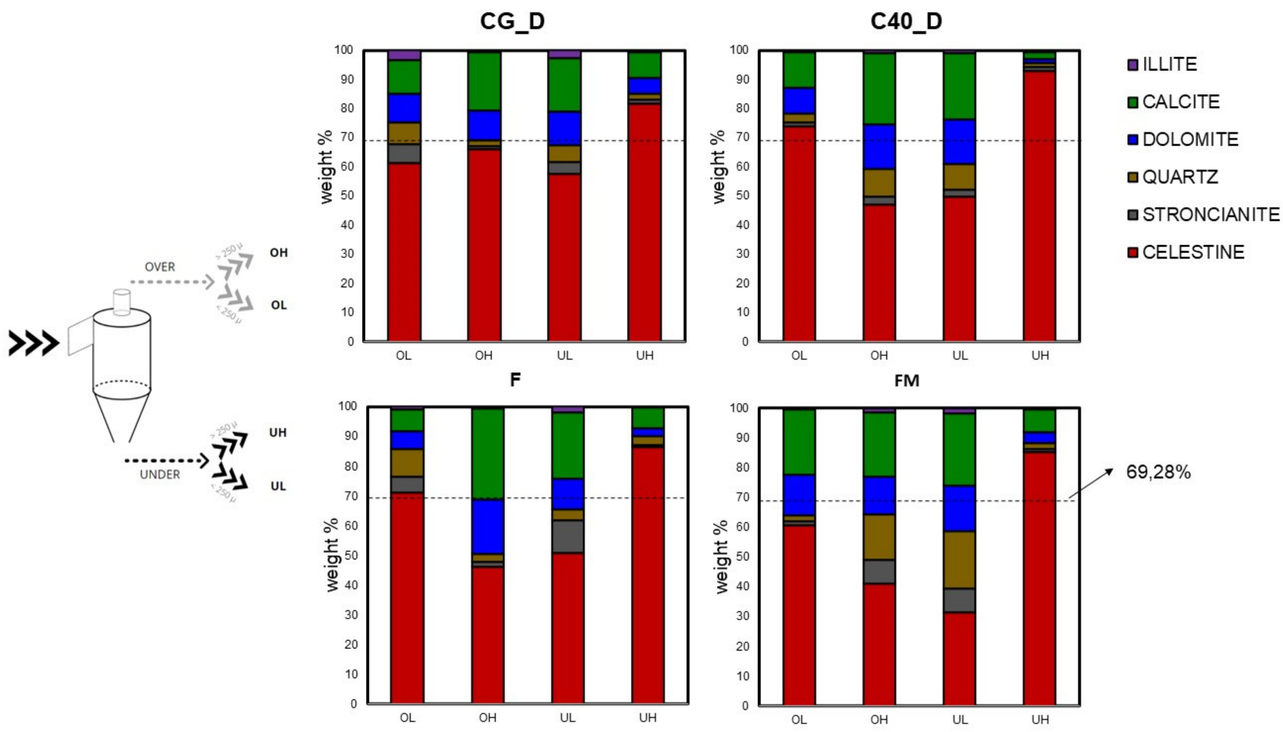

Figure S6. Bar Graph of mineral phases in each output stream.

Figure S7 shows schematically for each test and stream, the mass percentage of celestine detected by XRD.

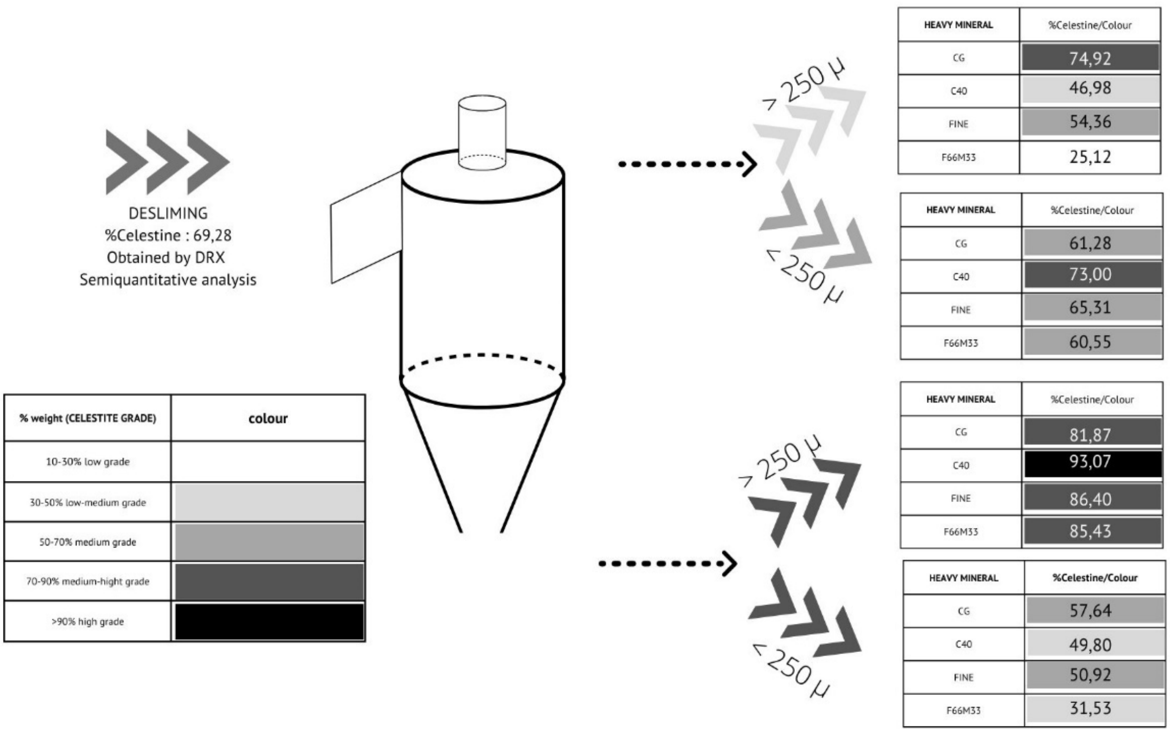

Figure S7. Setup schedule of celestine degree (run-on-mine).