CONVERSION OF QUARTZ-MINE WASTE MATERIAL TO EXPLOITABLE RESOURCES AND INDUSTRIAL PRODUCTS

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ABSTRACT

Northern Greece hosts a number of strategic industrial minerals which make an increasingly important part of the mining industry and commerce in Greece. Significant quantities of quartz-vein resources of varying quality are hosted by gneisses and schists mainly in Pre-Alpine metamorphic formations. The Greek mining company ELVIOR S.A. produces from its quarry and plant north of Thessaloniki, nearly 12,000 tpa, of which a pure white fraction of 3,000 tons is exported for polyester tile manufacturing (95% quartz and 5% polyester). A quartz powder (-200 mesh) of 2,000 tons is applied in fillers and ceramics industry and 7,000 tons have a local market for more conventional applications. The company is now developing a processing flow sheet for fluid inclusion removal, to produce ultrapure grades. Previous years quartz production led to stockpiling of about 200,000 tons of mine and processing tailings/by–products disposed as waste material. In the frame of an European Union funded project, mineral processing studies undertaken were focused on exploitation of quartz tailings/by-products to turn them into exploitable resources and commercial products. An industrial scale flow-sheet, including crushing, classification, grinding, attritor treatment, drying and magnetic separation was developed, to install a new processing plant, already in successful operation. In terms, of quartz tailings exploitation, whiteness and removal of iron content and mineral impurities (micas, chlorite, feldspars, iron oxides, sulfides) were attained to obtain industrial products. The recovery of marketable quartz from mine and processing tailings/by-products, except from solving an existing environmental problem and developing an almost zero-waste production line, it guarantees mine-life extension to another 15 years, in an area where quartz reserves are reported almost exhausted. The quality grades achieved to date, put already quartz in certain segments of the European and international market.

INTRODUCTION

Exploration for vein-quartz deposits, as well as evaluation of known prospects, in northern (Macedonia, Thrace) and central (Thessaly) Greece has been carried out by the Institute of Geology and Mineral Exploration (IGME) of Greece, for the implementation of the BRE2-CT94-1026 E.U. Brite – Euram II Programme entitled *"New industrial applications for quartz deposits indigenous to the Community"*. This completed project aimed at developing advanced exploitation techniques to produce ultra-pure quartz/silicon for high-tech application needs of the European market, using Greek vein-quartz as raw material (Arvanitidis et al., 1988).Targets were subjected to a succession of geological, geophysical, petrological, geochemical, as well as trenching and drilling studies and tests which resulted in the discovery of significant vein-quartz reserves amounting to 2,5 m.t. and the selection of prime targets for further evaluation. Along with the completion of the project the achieved quartz qualities in terms of elemental chemical impurities (Fe, Al, Ti, Na and K) appear feasible for the optics industry. (Arvanitidis and Kilias, 1997). Quartz veins are hosted by rocks belonging to the Serbomacedonian (SMZ), Pelagonian (PZ) and Rhodope (RZ) geotectonic Zones (Figure 1).

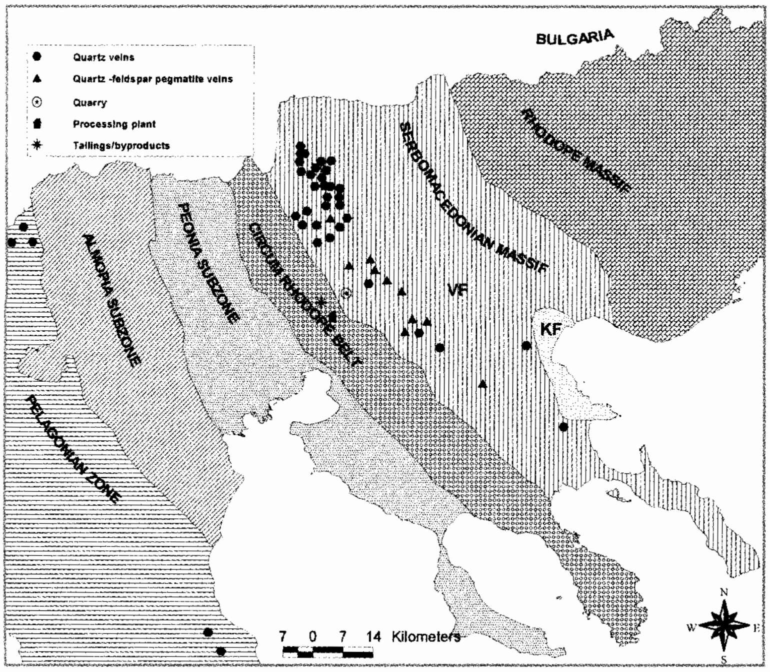

Figure 1. Quartz and pegmatite vein deposits, quartz mining and industrial operations in central Macedonia, N. Greece.

During the last 25 years, vein-quartz mining and processing operation activities, undertaken by the Hellenic Industrial Minerals S.A. (known in Greece as ELVIOR S.A.), led to stockpiling of about 200,000 tons of mine and processing tailings/by-products, disposed nearby as waste material. Company's quartz production was based on exploitation of a SMZ quartz vein deposit in the Kastri quarry (Figure 1) and beneficiation in Assiros processing plant (Figure 1). Some years ago Elvior faced the problem of mineable quartz resources, as reserves in the Kastri quartz deposit were reported almost exhausted. Company's main interest, as an industrial partner in the BRITE EURAM project, except from improving the quality (high – to ultra – pure grades) of its final quartz products, was to locate new exploitable resources. Geological exploration and feasibility evaluation led to discovery of potential quartz – vein deposits in northern and central Greece (Figure 1), where mining is already in operation. About 3,000 tons of quartz ore have been produced. At the same time the development of a new processing flow sheet made possible the recovery of commercial quartz from stockpiled tailings/by-products, to provide a cost – effective and easily accessible resource opportunity.

This communication will present industrially feasible dressing techniques succeeding to turn what is making today mine and processing waste, to exploitable resources.

GEOLOGIC SETTING

Quartz vein mineralization of the Palaeozoic or older SMZ occurs in its western lithostratigraphic and tectonic unit, the Vertiskos Formation (VF) (Figure 1). The VF is a NW-SE trending highly deformed and polymetamorphosed heterogeneous assemblage consisting of metasedimentary two-mica gneisses and garnet-, staurolite - and kyanite- bearing mica schists, meta-tholeiitic amphibolites, metagabbros, seprentinized ultramafics, anatectic granites and pegmatites (Kockel et al., 1977; Dixon and Dimitriadis, 1984; Sakellariou, 1989; Kourou, 1991; Sidiropoulos, 1991). Five metamorphic episodes (M1-M5) and four major deformation phases (D1-D4) have been recognized in the NW part of VF where most veins cluster (Figure 1) (Kourou, 1991; Sidiropoulos, 1991). The area has suffered Alpidic (Late Jurassic) deformation (D3) and regional metamorphism (M4) reaching upper greenschist facies conditions (T: 400-520 °C; P: 5-6 or 9 kb). This tectonometamorphic event was followed by post Jurassic deformation (D4) and retrogression under greenchist facies (M5) (T: 300-550 °C; P < 5kb). Post-D4 brittle phenomena have been ascribed to gradual uplift of the Vertiskos basement (Kourou, 1991; Sidiropoulos, 1991). Evidence for Hercynian (Amplibolite Facies – M3-D2 and M2 – D1) and pre-Hercynian (Eclogite Facies – M1) tectonic and/or metamorphic events exist locally.

VEIN GEOMETRY, MINERALOGY, DEFORMATION AND CHEMISTRY

Figure 1 shows the locations of the discovered and known veins of VF. Quartz veins routinely occur in two-mica gneisses and biotite gneisses occupying extensional fractures, except for rare cases when partly transect granitic bodies. They form disrupted and boudinaged steeply dipping (90° to 40°) bodies, striking NNW-SSE concordant to the regional schistosity. Veins measure from 30 up to 100 m in length, rarely reaching 300 or 500 m; thickness vary from 3 to 15 m. Veins are composed chiefly of milky or yellowish – brown quartz (up to 99,5 % by volume) with traces of white mica, sulphides, feldspar and iron oxides. The quartz grains are deformed, subhedral to anhedral, elongated and slightly dimensionally oriented, with relative dimensions of up to 8 mm in their longest axis and up to 4 mm in width. Vein quartz has suffered : a) An early episode of ductile deformation (quartz 1), post-dating the vein filling, attributed to emplacement of the veins in a dynamic tectonically active environment; b) Brittle fracturing that took place after the ductile deformation accompanied by cataclasis and recrystallization (quartz 2). SMZ raw quartz compositions show ranges of Fe = 1-28 ppm, Al = 22-73 ppm, Na = 12-37 ppm, K = 4 - 28 ppm, Ca = 11-40 ppm, Mg = 4-10 ppm, Ti = 1,4-4.8 ppm and Li = 0,1-0,9 ppm. The problem for electronic high – tech applications of quartz arises from high Na contents, and Na appeared to be the hardest element to degrade to quality requirements by the purification techniques used to successfully eliminate other elements (i.e. Fe, Al, Ca, Ti). Chemical removal of fluid inclusions and subsequent degradation to 2,39 ppm Na resulted to substantial quality improvement of quartz.

QUARTZ TAILINGS/BY-PRODUCTS COMPOSITION

Quartz – mine operation and processing has been undertaken in Northern Greece, by the Hellenic Industrial Minerals (Elvior S.A.), the last 25 years. During this period about 200,000 tons of milky quartz tailings/by-products were disposed and stockpiled as waste. The mineral composition of this –20 mm waste material consists predominantly by milky quartz but contains also various proportions of micas, feldspar and iron oxides. A fine–grained earth component makes a common matrix constituent to the previous minerals. The quartz grains show iron oxide staining, due to widespread limonitic coating. Removing the mineral contaminants and whitening the quartz from the iron oxides make the main processing effort to produce industrial grade milky crystalline quartz from quartz tailings/by-products.

MINERAL PROCESSING

Processing tests were carried out at IGME laboratories and at Elvior's own pilot plant installations, to develop an industrially feasible dressing flow sheet and to produce commercial quartz grade from quartz by-products. In terms of quartz by-products, beneficiation, whiteness, iron content and other minerals contaminants are considered to be the most important factors for a number of construction materials and tiles (Arvanitidis, 1998).

Laboratory beneficiation tests

Three by-product samples of two – 18 mm fractions produced by wet and dry sieving, respectively, and a -18 mm + 6 mm fraction, were subjected to beneficiation selection tests. A flow sheet, including crushing, classification grinding, wet screening, drying and dry magnetic separation (Figure 2) was developed to remove all mineral contaminants and to produce standard grades meeting the specifications of the tiles (artificial stone) and ceramics industries.

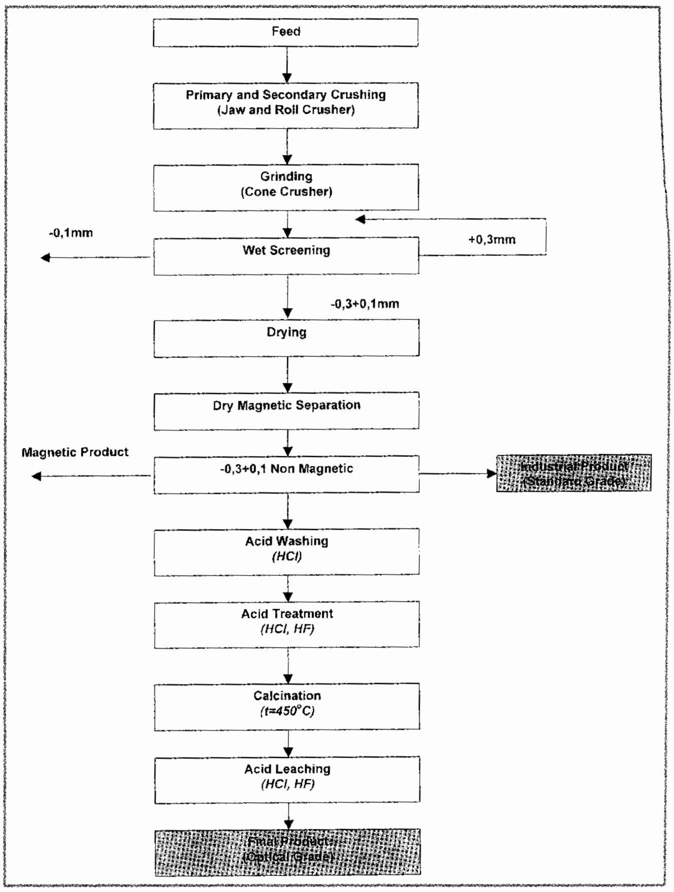

Figure 2. Quartz beneficiation flowsheet for industrial grade production and optical grade development.

Red surface – staining on the coarser grains was removed by scrubbing to reach acceptable quartz whiteness. Further purification could take place by applying acid washing and calcination, to produce optical grade quartz (Figure 2). The quality improvement in chemical composition from raw quartz to standard and optical grades is shown in Table 1.

Industrial flow sheet development

Mineral processing tests in laboratory and pilot plant scale were carried out by Elvior S.A. aiming :

- To select the most suitable flow-sheet for processing quartz tailings and to develop a pilot plant beneficiation technique to produce qualities free of grain-surface impurities.
- To select the optimum pilot plant technique for processing vein quartz for the production of ultra-pure quartz.

ppm	1			2			3			4			5			6	
	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B
Al	79,4	34,0	12,0	650,0	484,0	17,0	183,00	116,00	5,96	26,73	19,64	5,23	30,98	27,15	15,31	346,0	116,0
Ca	56,8	11,0	<0,5	32,0	22,0	57,0	2,36	1,65	0,25	6,59	5,30	1,98	8,03	5,58	0,87	58,0	205,0
Fe	49,7	7,0	3,0	745,0	19,0	4,0	32,10	21,52	0,19	15,76	11,24	0,34	21,30	14,12	0,38	157,0	55,4
Na	14,8	22,0	10,0	47,0	13,0	5,0	32,00	25,81	6,64	7,6	6,63	3,39	3,32	3,21	2,39	27,0	21,8
K	11,6	5,0	2,0	12,0	7,0	1,0	64,70	45,2	0,70	12,78	7,54	0,49	8,24	5,96	0,84	70,0	41,5
Li	0,4	0,4	0,4	0,2	0,7	0,7	0,16	0,15	0,14	0,36	0,36	0,23	0,41	0,4	0,55	<0,2	0,1

Grade C : Raw material; Grade B : Crushing, grinding, classification, water washing, magnetic separation; Standard grade
Grade A : Acid washing and calcination; Optical grade.
Table 1. Chemical composition of raw and beneficiated quartz samples from Northern Greece.

In the first stage, laboratory scale tests on tailings samples of 20 kg each, were carried out in different manufacturing companies of magnetic separators. Additionally the same samples were chemically and mechanically processed. The results of chemical processing were unacceptable while the mechanical processing tests gave satisfactory results. A wet scrubbing method was used by the company ARP (Leoben, Austria) with a WEMCO Attritor. This method gave very good results by delivering a non magnetic product of 8-4 mm grain size fraction consisting of 80% quartz and 20% water, processed for 1 min. Afterwards the product was subjected to wet screening using 1 mm sieves.

In a second stage some pilot and industrial scale tests were carried out at Elvior's facilities. The treatment of large quantities of quartz by-products was necessary for optimizing and developing an industrial scale pre-concentration line and for receiving quartz concentrates of sufficient amount and purity to undergo further beneficiation progress.

- Bulk sampling of pre-concentrated quartz material was conducted for demonstrating pilot plant beneficiation tests by using various types of high-force magnetic separators.
- Bulk sampling of pre-concentrated quartz material from mined veins and by-product tailings was conducted to serve pilot-plant testing for the final installation and development of Elvior's operating processing plant to produce high-purity qualities.

In the frame of the objectives of the mineral processing task in the BRITE EURAM project, Elvior conducted and scaled-up beneficiation testing in terms of adapting the required modification and unit installation in the existing plant to further commercialize its quartz products. The intention was through a cost-effective and productive way to turn stockpiled quartz tailings to exploitable resources and to upgrade quartz raw materials, in general. The targeted quartz specifications are confined by certain industrial applications comprising: (a) whiteness (b) iron content lower than 0,05 wt% and (c) low content of other impurities. The actions undertaken to develop and compound the overall operation process are referred to in the following stage.

Pre-concentration stage

On the basis of laboratory beneficiation testing undertaken by IGME, but also using own pilot plant tests, Elvior developed a pre-concentration flow-sheet section before final processing. During this stage bulk samples of quartz were originally beneficiated, pre-concentrated and prepared to underdergo total processing, to achieve maximum upgrading. The pre-concentration flow sheet line included:

For quarried quartz-vein raw material:

- Grizzly vibration screening
- Jaw crushing
- Vibrating screen under water pressure and washing to remove the fines
- Handpicking conveyor
- Cone-crushing and +6 mm shieving
- Production of 0-6 mm fraction

For quartz by-products (tailings) material (-18 mm), the same pre-concentration processing line was applied excluding jaw crushing. Specific mechanical treatment techniques comprised:

- Screening and washing to produce 4-18 mm fraction
- Handpicking (4-18 mm)
- Close circuit cone-crushing and vibration screening to produce 0-6 mm fraction. The 0-6 mm fraction was prepared to undergo a second stage of processing including magnetic separation and other new techniques to define the final and total flow-sheet development to be applied and installed inside ELVIOR's existing plant.

Main concentration stage

Particular attention was paid to testing independent techniques to be optimized and integrated in the final flow-sheet.

The selection of the magnetic separation process had an important role in the designing and developing of the flow-sheet. The selection of the suitable equipment and also the right process (dry or wet), was crucial for the upgrading level of the final product. Eriez Magnetics Europe, was asked to conduct trials on the magnetic purification of crushed quartz. A sample of

<6.0 mm attrition scrubbed quartz was supplied for test. The sample was dried and screened at 2.0 mm to remove fine fraction. Tests were conducted on a dry sample and a sample with 1,0% moisture, by using a rare earth roll separator.

The results obtained is shown in Table 2.

Parameter	2-6 mm fraction, dry	2-6 mm fraction, 1,0% moisture
Feed	5,970 g	3,612 g
Roll magnetics	187 g	1,510 g
Roll magnetics	28 g	2,510 g
Product	5,865 gr	2,534 gr
Weight loss to magnetics	1,6%	28,2%
feed rate	5,4 tph/m	3,6 tph/m
belt speed	0,5 m/sec	0,5 m/sec
belt thickness	0.15 mm	0.15 mm

Table 2. Magnetic separation process.

Operational settings were the same for both tests. From the above testing it was visually concluded that the sample supplied after attrition scrubbing appeared whiter than previous samples. Separation on completely dry material gave a good recovery of schist with minimal quartz loss. However the addition of 1,0% moisture, changed the characteristics of the material causing smaller particles to stick to the surface of the vibrator feeder, stick to the belt and feed in an erratic manner. An additional effect was the high loss of good material to magnetics (28%) caused by material sticking to the transport belt. Although the capital and operational costs of drying are high, it is necessary to achieve moisture levels of less than 0,5% for having acceptable magnetic separation results. It was found that feeding directly the material with water to the attrition created a lot of dilution problems and gave poor results.

Except for the application of magnetic separation to remove impurities of iron-bearing mineral species (e.g. micas, iron-oxides and/or hydroxides) and other magnetic compounds, an additional technique was searched to purify and whiten the surface of quartz grains from staining and coating of iron oxidation. An inventive method combining washing and scrubbing techniques, with and without water recycling, was tested but the results were not completely satisfactory. The problem was then presented to the Austrian Company Aufbereitung, Recycling, Pruftechnic Ges.m.b.H. (ARP) which tested a method combining attrition and magnetic separation techniques to purify and whiten quartz. A report was submitted concluding the results of quartz beneficiation testing undertaken on two Elvior samples of 500 and 600 kg. The basic feature of attrition machines is that size reduction is achieved by particles breaking each other after they have acquired the necessary energy from a solid or fluid impeller. The main advantage of attrition machines is that they can produce very small products (10 mm or less) and the product size can be controlled within a narrow range.

The 600 kg quartz sample was subjected to attrition treatment by using single and double-cell attritor. Testing on 0-6 mm fraction of quartz grains resulted in visual upgrading. It was calculated that the residence time in the attrion cells for a feed of 6 t/h will be 5,56 minutes. Representative samples of attrition beneficiated products were delivered to Eriez Magnetics. On the other hand, ARP carried out magnetic separation trials by applying in-house facilities of IMPOSYS high-force magnetic separator. Magnetic separation is more effective on dried (moisture <0,2%) products after attrition. Obviously the results received from the two magnetics separation tests mentioned above were equally satisfactory for both ERIEZ and IMPOSYS equipped magnetic separators. The quartz derivates received from ARP, were furthermore milled by iron-free balls to produce commercial fractions of 0,1-0,3 mm, 0,3-1,2 mm and -200 mesh. The material which was produced by ARP when it is mixed with 5% polymers is convenient for the construction of floor tiles and kitchen tops, but is also suitable for different metallurgical applications.

More scrubbing tests were carried out with the -6 mm material. The samples before testing, contained a certain amount of clay and schist which gives a coloured mixture. A preliminary washing at 25% solids was made to simulate the operation of a sand preparation machine, in which the free clay (-0,1 mm) overflows the tank and the sands are raked by the spiral, to give the 70-75% solids material required for the best attrition process. A loss in weight of 8% has been achieved by this first washing stage. Attrition was performed in a 10 litters cell during 3 minutes. A second washing of the sands was made to remove the remaining clay with a loss in the total weight of 6%. The final product looks acceptable, recording an 86% recovery and a grain size distribution. which is described in Table 3. The conclusion was that it is better to feed the attrition cells from the water classifier in order to have a pre-washed product and better dosification by the spiral at a constant rate of 65-67% solids which is critical for the best efficiency of the attrition process. It was found that feeding directly the material with water to the attriton created a lot of dilution problems and gave poor results.

The underflow of the classification screen to minus 1 mm cannot go to the thickener because it created segregation and sedimentation problems of the -0,1 mm clay. At the same time, the final product 1 x 0,1 mm is clean and can be stocked for future application. If this material is mixed again with clay, the

Grain Size	Weight (gr)	% Percentage
+ 5 mm	14	1,67
+ 2 mm	485	57,86
+ 1 mm	177	21,12
- 1 mm	162	19,33

Table 3. Grain size distribution (sample 838 gr).

final product will be a non-reusable tailing. The underflow from the cyclone can be stocked in a pile directly on the ground at 60-70% solids, and the water recovered by a drainage system of sloped bottom going into sump and pumped to the thickener.

New scrubbing tests carried out at Elvior and ARP facilities resulted in some changes in the final flow-sheet (Figure 3). The new flow-sheet includes 2 Attrition machines for improvement of the whiteness of the final product an Ortner dewatering machine in order to lower the moisture content of the -1 mm final product to 6-8% (Figure 2). The Ortner machine is most suitable and unmatched for dewatering sand products coming from wet crushing, classifying tanks or from hydrocyclones. Fine slimes (which might be clay in the quartz) will be taken out of the sand at the same time. Capacities may vary and the finer the product is, the less will be the actual throughput capacity. If the feeding rate to the attrition machine is 7 t/h the -1 mm fraction will be approximately 3,5 t/h. The water flowsheet was equipped by spiral classifier, screening machine, hydrocyclone and pump.

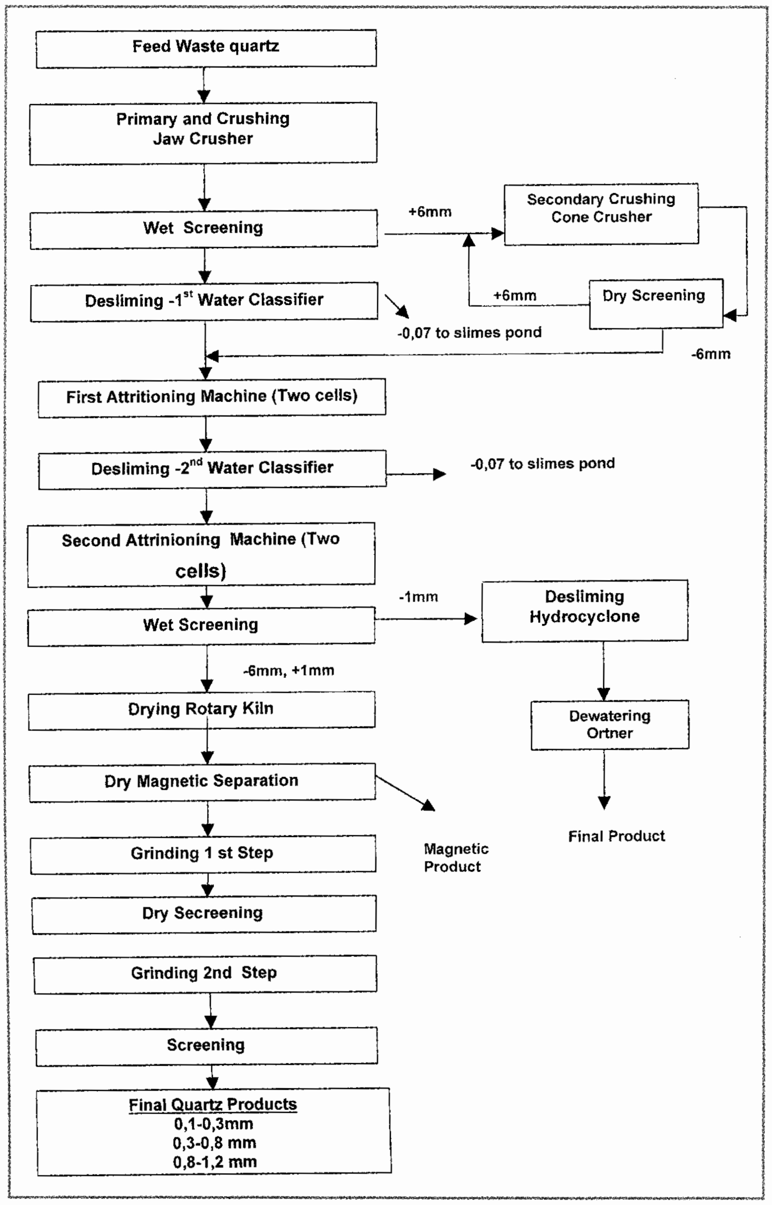

Figure 3. Integrated flow sheet for the beneficiation of quartz tailings.

DISCUSSION AND CONCLUSION

In Greece, due to the strict environmental legislation a minimum period of at least two years is needed for a company to obtain a concession for exploitation of a quarry. This fact in relation to quartz depletion in the deposit of the Kastri quarry, was the main initiative for Elvior S.A. to consider the exploitation of 200,000 tons of quartz tailings.

The final flow sheet included crushing, screening, water classification, double attrition treatment, wet screening, dewatering, drying and magnetic separation (Figure 3). The decision for the selection of this flow sheet was based on extensive laboratory and pilot scale tests which was carried out at Elvior and different other manufacturing companies of ore dressing equipment. The main benefits of the development of this new flow sheet was:

- the solution of a very important environmental problem by turning approximately 200,000 tons of quartz tailings to valuable commercial products;
- continuous product supply for a period of more than 15 years;
- decrease of the production cost; and
- improvement of the quality of the final product.

Cold and hot commissioning tests of this new plant was carried out in January 1998 following a successful construction period of six months. The new beneficiation plant was installed in a three floor building and was consisting of the following equipment : two attrition machines, two water classifiers, one vibrating feeder, four belt conveyors, one dewatering disk, two slurry pumps, one hydrocyclone, one dewatering screen and one magnetic separator. There are four different water circuits for the attrition machines and the screens. The water used for cleaning the quartz tailings is also recycled and reused through three settling ponds. The operation of the plant which is fully automated is controlled from the central control panel. The total investment for this new plant exceeded the amount of 180 KEURO, while four operators were hired for every shift. The production of clean quartz is 5,6 tons/h (+1 mm, - 6 mm) and 1,4 tons/h (- 1 mm). The – 6 mm + 1 mm fraction of washed quartz is transported to a grinding plant where after drying passes through a dry magnetic separator RE40-2 Rare Earth Roll Separator and the final impurities are removed. The iron content is lower than 0,05 wt% and the whiteness is very good. The final grain sizes (after primary and secondary grinding and screening) result to an absolutely white quartz exported to Israel, Italy and Spain.

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