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Quartz deposit's requirements for high-purity quartz production

Annotation

Relevance. High-purity quartz (HPQ) is one of the important materials for the high-tech industry. Despite the widespread occurrence of quartz deposits, only a few of them can be used for the HPQ production.

The purpose of the work is to determine the criteria for quartz deposits as a potential raw material base for the HPQ production.

Outcomes. Six main criteria and their values for quartz deposits as a raw material base for industrial HPQ production are determined.

Findings. The matrix of criteria presented in this article makes it possible to quickly and cost-effectively carry out an express assessment of quartz deposits as a potential raw material base for the HPQ production. Such a matrix can be used not only for the assessment of new deposits but also for the revision of previously explored deposits, taking into account current high-tech industry requirements.

Keywords: high-purity quartz, HPQ, quality criteria, HPQ deposit, HPQ manufacturers, high-tech industry, raw material base, Kyshtym deposit, Sibelco, The Quartz Corp.

Introduction

The widely used term "high-purity quartz" (HPQ) which describes the product obtained from quartz ore, is determined not only by the genetic or mineralogical properties of quartz raw materials, but also by a whole range of parameters: applicability in various industries, technical and economic parameters of HPQ's deposits, production cycle, technological possibility of quartz ore beneficiation, etc. In this regard the applicability of the term "high-purity quartz" has been changed during last decades.

Taking into account above the potential raw material base for the HPQ production should be considered in the context of genetic, mineralogical, technological and commercial criteria.

As the HPQ production itself requires significant capital investment and has a long investment cycle, determination the right source of quartz raw materials among the widest range of quartz deposits is critical. The cost of mistake and wrong choice at the stage of planning of the HPQ production is very high. This circumstance determines the need to create a matrix for evaluating quartz raw materials which allows you to quickly and with minimal cost to understand the possibility of using a quartz deposit for the HPQ production.

Based on the long-term experience of Kyshtym GOK (since 1966) and Russian Quartz (since 2011) in the development of the Kyshtym quartz deposit (Russia), as well as the analysis of data on other world HPQ manufacturers, the following criteria are identified in the preliminary assessment of the technological suitability of quartz deposits for the HPQ production:

1. Genetic criteria

1.1. Type of quartz raw materials

In the USSR and later in Russia the priority type of quartz raw material for the HPQ production traditionally was a vein quartz. Significant work carried out on the search, testing and industrial operation of quartz veins has made it possible to accumulate a large array of data on various deposits. World experience shows that in addition to vein quartz, quartz of deposits of other genesis can also be involved in the production of high-purity quartz. Such deposits include some kind of Alaskite granites and pegmatites [1].

This is confirmed by the fact that all industrial suppliers, both operating at the time of writing this article and supplying the HPQ in the last 15 years, relied on the following types of raw materials:

- Alaskan granites (Sibelco (ex. UNIMIN));
- pegmatites (Sibelco, The Quartz Corp, Norwegian Crystallites AS);
- vein quartz (Russian Quartz LLC, Polar Quartz JSC, Kyshtym GOK JSC).

Other types of quartz raw materials (quartz sands, quartzites, etc.) are considered to be technologically or economically unsuitable for the production of HPQ. For example quartz of quartzite, despite its relatively high chemical purity and quartz content in the ore more than 98%, often has a relatively fine-grained particle size and is found in close intergrowths with other rock-forming minerals [1], including a large number of inclusions inside the grains, which does not allow modern methods of industrial beneficiation to effectively achieve the required quality. Rock crystal, which used to be one of the main types of raw materials for the HPQ production in the past, is also not considered for industrial usage today [1].

It should also be noted that the suitability of quartz ore for the production of high-purity quartz is not always determined by the minimum content of associated minerals in the ore. There is point of view that the less mineral inclusions exist in quartz ore (mineralization), the more likely that quartz is suitable for the production of high-purity quartz. With this point of view are connected a large number of negative attempts to test objects of milky-white vein quartz, which is sometimes distinguished by an extremely low content of mineral impurities (quartz content at the level of 99% in the ore), as well as high chemical purity. Practice shows that the monominerality of the ore mass cannot serve as the main criteria in the case of the HPQ raw material base. For example, ore of the Spruce Pine deposit (a deposit where Sibelco (USA) and The Quartz Corp. (USA) are based), contents up to 75% minerals impurities (mica, feldspar etc.) [2,3,4]. It means that the content of the quartz in Spruce Pine's ore is significantly less than the content of mineral impurities.

The key role in the suitability of quartz raw materials for the HPQ production is not the quality of the ore in terms of quantity of mineral inclusions but the quality parameters and homogeneity of the properties of the quartz grains which compose this ore.

2. Mineralogical and technological criteria

2.1. Quartz quality parameters (impurities of different nature in the constituent grains of quartz and in the quartz ore itself)

From a technological point of view impurities in quartz ore which determine the quality of quartz and its applicability as HPQ can be divided into the following types [5,6]:

Gas-fluid inclusions (GFI). The presence of GFI in quartz is determined by the capture of fluids during the growth of quartz grains (primary inclusions) as well as the healing of cracks in existing grains with mineralized solutions (secondary inclusions) [1,5]. The content of GFI primarily determines the quality of quartz glass produced from HPQ in terms of such defects as the bubbles, clusters of bubbles, capillaries, etc., and this is as important a parameter as the chemical purity of quartz. The content of GFI in quartz raw materials allowed to separate two fundamentally different types: milky-white and transparent quartz [5]. Currently there are no economically feasible purification operations that make it possible to produce transparent quartz glass from milky-white quartz [6].

Structural impurities and micro-mineral impurities in quartz grains. Structural impurities are impurity elements embedded in the crystal lattice of natural quartz. Basically, such elements are Li^{+}, Na^{+}, K^{+}, Al^{3+}, Ti^{4+}, Fe^{3+}, Fe^{2+}, B^{3+}, P^{5+}, as well as H in the form of OH^{-} and bounded water [4].

Micro-mineral impurities in quartz grains are inclusions of foreign minerals less than 1 μm in size [6], captured or formed inside the grains during growth and subsequent recrystallization. The mineral composition of such inclusions is very diverse and as a rule depends on the composition of the host rocks and the conditions of formation of the quartz deposit.

Macro-mineral impurities as part of quartz ore. This group of impurities is determined by the minerals that make up the quartz ore together with quartz. They are represented by individual grains and intergrowths of external minerals, intergrowths with quartz grains, plaque on the surface of quartz grains, fragments of host rocks, including those captured during the formation of quartz deposit, etc. The main distinguishing feature of macro-mineral impurities is that they can be separated from quartz grains by using standard processes of purification. As well as micro-mineral impurities, macro-level impurities can have a diverse composition and depend on the composition of the host rocks [5].

GFI, structural impurities and micro-mineral impurities are almost impossible to remove without complete destruction of the quartz grain. Their content in quartz serves as criteria for the limits of purification of quartz raw materials and, accordingly, the possibility of application in the HPQ production. The GFI content determines the level of defects in the quartz glass produced from HPQ in the form of bubbles and capillaries, and the structural impurities determine the maximum achievable chemical purity of HPQ.

Macro-mineral impurities can be removed almost completely with modern beneficiation methods. Their quantity and composition determine the optimal technological scheme for the purification of quartz raw materials.

In practice the term "monofraction" is used to characterize the purity of quartz itself. Monofraction refers to carefully selected quartz individuals with a purified surface. The particle size distribution of the monofraction should correspond to the size of the raw material prepared for beneficiation. It is not possible to obtain quartz concentrates of higher quality than monofraction by traditional enrichment methods [6] (except for the use of the hot chlorination method). De facto, the separation of monofraction is a simulation of the maximally enriched material, completely free of mineral macro-impurities.

The analysis of the content of HPQ and the chemical composition of the monofraction allows us to conclude that quartz is suitable for the production of HPQ with a very high degree of reliability and to exclude technological factors that affect the quality of HPQ.

<u>*The content of GFI.*</u> In our practice the method of measuring the light transmission coefficient (T, %) of quartz grains in an immersion liquid is used to measure the content of GFI. The light transmittance of quartz

which is used for the HPQ production should be at least 80% [7]. For example the coefficient of light transmission of quartz from the Spruce Pine deposits and vein 175 of the Kyshtym deposit is in the range of 84-86% (Table 1).

Table 1. Results of Light Transmission Measurements in Samples of HPQ Grades from the Spruce Pine Deposit and Vein 175 of the Kyshtym Deposit

Deposit	Type of Raw Materials	Producer	Sort	Light transmittance, T%
Spruce Pine	Pegmatites	The Quartz Corp	NC4A	84,5
Spruce Pine	Alaskan Granites	Sibelco	IOTA 8	84,8
vein 175 of the Kyshtym deposit	Vein Quartz	Russian Quartz	RQ-2K	85,1

It should be noted that the GFI in some types of raw materials, for example, in granulated vein quartz, is localized in the intergranular space and along intragranular cracks [5,8], and is easily opened and removed during beneficiation. Partially GFI, localized in quartz grains, can also be exposed during calcination processes, but the efficiency of such operations is insignificant.

Chemical composition. The chemical composition of the monofraction is mainly determined by the content of structural and micro-impurities. The effect of GFI on the chemical composition of quartz with light transmission of more than 80% is insignificant

Depending on the application, customers have different requirements for the chemical purity of HPQ, but in general, current quality standards say that the total content of regulated impurities in the HPQ should not exceed 20 ppm. At the same time some industries require the content of certain elements within very limited parameters – for example, the iron content in HPQ used in photovoltaics should not exceed 0.5 ppm, and the content of boron and phosphorus should not exceed 0.1 ppm. For the semiconductor industry, the iron content should be no more than 0.2 ppm, and the copper, chromium, manganese and nickel content for the most critical applications in the semiconductor industry should be less than 0.005 ppm for each of these elements.

Previously the purity of monofractions and industrial HPQ grades from one deposit can be very different due to the imperfection of the enrichment technology. But currently visual incpection of the most purified HPQ grades shows almost complete absence of mineral impurities, which indicates that the maximum level of purification from macro-impurities has been achieved by existing technological solutions. This means quality equality between such concentrates and monofractions. At the same time the overall chemical purity of HPQ has reached the same level as that of artificial quartz crystals (AQC) grown by the hydrothermal method. There is reason to believe that the level of the content of the sum of impurities of 7-8 ppm is the minimum limit for HPQ, since there are currently no known industrial deposits with more pure quartz.

The chemical composition and the sum of impurities in the most purified HPQ grades produced by leading manufacturers in 2023 (without the usage of the hot chlorination method) and artificial quartz crystals produced by JSC "South Ural Plant Krystall" are shown in Table 2

Table 2. Chemical composition of HPQ (not hot chlorinated) of the world's leading manufacturers and artificial quartz crystals produced by Plant Kristall JSC, Yuzhnouralsk (ppm)

Element	Manufacturer/Raw Material Type/Grade			
	Sibelco [9]	Russian Quartz [10]	The Quartz Corp. [11]	Plant Krystall [12]
	IOTA 4	RQ-2K	NC4A	Chemically Pure Quartz
Al	8	3,9	13	< 5,0
B	< 0,05	0,07	< 0,1	
Ca	0,7	0,12	0,5	< 0,6
Cr	0,007	< 0,01	< 0,01	< 0,1
Cu	0,004	< 0,010	< 0,01	< 0,1
Fe	0,3	0,2	0,2	< 0,5
K	0,4	0,13	0,5	< 0,5
Li	0,2	0,3	0,4	< 2,0
Mg	0,07	0,05	< 0,1	< 0,1

Mn	0,013	0,004	< 0,1	< 0,1
Na	1,0	0,3	0,8	< 2,5
Ni	0,002	< 0,01	< 0,01	< 0,1
Ti	1,4	2,9	1,2	< 0,4
Sum of impurities	**<12,1**	**<8,0**	**<16,9**	**< 12,0**

2.2. Quartz grain size in ore

In addition to the chemical purity itself and the absence of GFI, it is necessary to take into account the size of the quartz grain. The standard particle size distribution in HPQ deposits is currently determined by the basic fraction of +75 - 300 μm. The average size of the constituent grains should not be significantly less than 200 μm. Otherwise, after mechanical disintegration, conglomerates of several "unopened" grains will be present in the concentrate, which significantly increases the presence of mineral impurities in the intergranular space of such conglomerates, which ca not be removed by the enrichment processes and lead to a loss of quality of the HPQ. Information on the size of quartz grains in the known HPQ deposits is given in Table 3.

Table 3. Size of constituent quartz grains in HPQ deposits

Deposit	Manufacturer	Type of Raw Materials	Size of constituent grains
Spruce Pine	Sibelco, The Quartz Corp.	Pegmatites	Medium size > 1.25 mm [3]
Spruce Pine	Sibelco	Alaskan Granites	Medium size 1.25 mm [3]
vein 175 of the Kyshtym deposit	Russian Quartz	Vein Quartz	The average grain size is 1.2 mm. 20-35% of the grains are 2-5 mm in size, up to 60-80% - 0.1-0.4 mm [13]
Nedre Oyvollen	Norwegian Crystallites AS	Pegmatites	Medium 6 mm [1]

3. Commercial Criteria

3.1. Homogeneity (homogeneity) of quartz and quartz ore

The homogenity of quartz quality parameters (primarily the parameters of chemical composition, the content of GFI and quartz grain size) in the entire volume of the deposit is one of the important criteria when considering the deposit as a raw material base for the HPQ production. This is due to the request of customers related to the undesirability of deviations in the quality parameters of the supplied HPQ.

Testing new quartz raw materials and agreeing on chemical composition specifications involves lengthy and costly certification procedures (in the semiconductor industry, the certification period can be up to three years). At the same time, according to quality management standards, it is impossible to use HPQ before the end of certification, which can lead to a break or a complete reduction in HPQ supplies.

The content of GFI, structural impurities and micro-impurities in natural quartz can vary significantly, even within the same deposit. Such fluctuations in the properties of quartz are even more significant when comparing different veins within the same deposit. Such variability directly affects the melting properties of HPQ and the quality of the manufactured quartz glass and requires testing for each new vein and constant monitoring of the properties of those already in operation.

The heterogeneity of composition of mineral macro-impurities in the quartz ore has a less importance, but this factor also plays a role, since it requires the search for and constant change of technology of purification, which plays a negative role both from an economic point of view and from the point of view of consistency of quality.

Taking into account the above, it is impossible to consider the aggregate of quartz veins in the deposit as a single raw material base. For the purposes of HPQ production, each quartz vein in deposit must be evaluated as a separate object.

3.2. Proven quartz ore reserves

According to a number of sources, the development of the HPQ deposit is economically justified with ore reserves of more than 80 thousand tons [1,15].

In general, these data are confirmed by the data on the leading HPQ producers (Table 4), but it should be taken into account that, a large number of technical and economic parameters are important when you consider this criteria, ranging from the amount of investment and the volume of mining operations to the current HPQ price level.

In addition, taking into account the volume of capital expenditures, the duration of the investment cycle, as well as the duration of testing and certification of the HPQ, the reserves of the deposit should ensure the operation for a period of at least 15-25 years, depending on the intensity of production and processing volumes.

Table 4. Reserves of quartz raw material deposits used for the industrial HPQ production, (in thousand tons)

Name	Producer		
	Sibelco	The Quartz Corp	Norwegian Crystallites AS
Deposit	Spruce Pine	Spruce Pine	Nedre Oyvollen
Reserves, thousand tons	> 10,000[9]	> 10,000[10]	> 170 [1]

4. Matrix of Criteria for Preliminary Assessment of HPQ deposit

The above analysis of the quartz deposits makes it possible to form a matrix of criteria for a preliminary assessment of the potential suitability of quartz deposits for the HPQ production (Table 5).

Table 5. Matrix of criteria and values for preliminary assessment of the deposit as a potential source of HPQ

№	Name of the criteria	Value
1.	Genetic type of deposit	Vein quartz, Pegmatites, Alaskite
2.	Light transmission of quartz monofraction, T%	> 80
3.	Sum of impurity elements in monofraction, ppm	< 20
4.	Average quartz grain size, μm	not less than 200
5.	Homogeneity of quartz quality parameters in the mining object (light transmission, chemical composition, granulometry)	Yes
6.	Confirmed quartz reserves at the deposit, thousand tons	At least 80

It should be noted that this matrix in Table 5 is offered for preliminary evaluation only. Upon detailed consideration and over time, the values of these criteria may change depending on specific HPQ deposit. Thus, technical and economic conditions (price and degree of HPQ purification, mining and technical conditions of production, etc.) affect the minimum required volume of confirmed HPQ reserves.

In the future, new industrial types of raw materials, such as certain varieties of quartzites, may appear [16].

On the other hand, the ever-tightening requirements of the high-tech industry may significantly reduce the scope of applications of quartz from certain deposits. An example is the Nedre Oyvollen deposit (Norway), the basic source of raw materials for Norwegian Crystallites AS. After the chemical purity requirements for HPQ changed from "less than 50 ppm" in the early 2000s to "less than 20 ppm" in the 2010s, Nedre Oyvollen quartz (with a total impurity content of more than 35 ppm) seems to be pushed out of the HPQ market, remaining only in narrow applications as EMC fillers.

Conclusion

The application of the matrix of criteria for the preliminary assessment of HPQ deposits makes it possible to select potential quartz deposits for the HPQ production in accordance with current industry requirements and with minimal time and costs (and if necessary with minimal additional testing of already known deposits).

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