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USES AND SPECIFICATIONS OF SILICA SAND

by

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USES AND SPECIFICATIONS OF SILICA SAND

Abstract

The chemical, physical, and mineralogical specifications of many industrial sand products are outlined in this report. Most of the specifications concern high purity silica sand used as a raw material for the manufacture of glass, silicon carbide, and soluble silicates for the chemical industry, and for molding sand, hydraulic fracturing sand, and filter sand. Quality requirements for sands of lesser purity used for special purposes such as sandblasting, abrasives, and building products also are given. The specifications were obtained from consultants, plant operators, and sand producers across Canada, and from published works on the subject.

INTRODUCTION

The Research Council of Alberta has received numerous requests for information on silica sand uses and specifications from prospective suppliers interested in evaluating local deposits of sand for their industrial potential. This report is designed to meet this need and stimulate the development of silica sand resources within the province wherever possible. In compiling this information it has been necessary to contact each industrial user and in some cases to analyze suppliers' products. It should be understood that in this compilation many of the specifications given are general and may have to be modified to meet the preferences of individual users. It is possible in some cases that specifications might be relaxed to permit exploitation of less expensive local sand sources, although the general trend is for industrial sand specifications to become increasingly stringent as the users demand greater uniformity and chemical purity.

At the present time most industrial sands are imported into the province for use in the manufacture of glass and glass fibre, in foundries for molding purposes, for water filtration, for hydraulic fracturing, and for high quality sandblasting. Of the companies involved, the glass industry, currently the major user in Alberta, has the most exacting specifications.

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DEFINITION AND PROPERTIES OF SILICA SAND

The term "sand" is applied to loose granular materials falling within a specified particle size range (Appendix B). As such, sand has a strictly textural connotation, for the constituent particles can be composed of a wide variety of artificial or natural substances. However, conventional use of "sand" without qualification implies a granular material composed of natural mineral particles, among which quartz (SiO_2) is an abundant if not the dominant constituent.

The widely used terms ***silica sand, quartz sand,*** and ***industrial sand*** are commonly applied without exact definition. They are to some extent interchangeable, referring to granular materials composed primarily of quartz with minor amounts of other mineral or organic constituents such as feldspars, carbonates, iron oxides, micas, clay minerals, and coal. The terms also apply to quartz-rich sand used for a variety of industrial materials or processes, as opposed to sands used for large-scale construction purposes.

Silica or quartz sand is evaluated for industrial use on the basis of its composition and physical properties. The specifications for these properties vary according to the use to which the sand is to be put, chemical composition is of paramount importance in glassmaking, whereas grain angularity and hardness are important for sandblasting. The more important properties of industrial sand are described below.

Clean: normally refers to a sand with a low or negligible silt, clay, and organic matter content.

Color: a mass property related to mineral composition and thus in a general way is an index of purity (e.g., a brownish or orange color normally indicates the presence of iron oxides). It is a particularly important factor to be considered in the manufacture of lime-silica brick.

Effective grain size: see grain size (below).

Grain size: an important textural property for most industrial sand uses. It normally is determined by screening the particles on a series of standard wire sieves (Appendix B). ***Effective grain size*** is a statistic used in plotting the ***uniformity coefficient*** (below and Appendix B).

Refractoriness: is that property associated with the ability of a material to withstand high temperatures without fusing or breaking down. It is an important factor in foundry sand, furnace sand, core sand, and other sands subjected to high temperatures.

Shape: a textural property that includes the concept of grain roundness (or angularity). It is an important factor in assessing sand for several uses, notably blasting sand and hydraulic fracturing sand.

Sorting: a textural property that describes the ***range*** of particle sizes in a sand (see uniformity coefficient below).

Soundness: refers to grain toughness in handling and processing. Grains should be hard and not prone to fracture for most uses.

Specific gravity: the specific gravity of pure quartz grains is 2.65. A lower specific gravity may indicate the presence of "light" impurities or grain porosity. A higher value indicates the presence of heavier minerals such as carbonates, iron oxides, etc.

Texture: refers to the size, sorting (or uniformity), and particle shapes of sand aggregates. See Appendix B for additional comments.

Uniformity coefficient: a measure of grain sorting (above) determined from the cumulative size-frequency curve of sand (Appendix B).

Void ratio: relative amount of interstitial or pore spaces in a bulk sand. The percentage of voids (or porosity) is a function of grain sorting and shape and can be determined using several procedures. It is an important property for molding sands.

Weight: is a function of void ratio and specific gravity. It is usually expressed in pounds per cubic foot or pounds per cubic yard, the weights of bulk sand vary from 2,200 to 4,000 pounds per cubic yard.

CLASSIFICATION AND USES OF SILICA SAND

Silica sand is used in many commercial processes and products and, therefore, is commonly classified on the basis of its industrial applications (Ladoo and Myers, 1951). Broadly, the major industrial uses of silica sand can be categorized as follows:

(1) as an ***abrasive*** in blasting and scouring sand, and in certain types of grinding and polishing materials;

(2) for various types of ***building products*** such as roofing tile and sand-lime brick;

(3) in ***glassmaking;***

(4) in ***hydraulic fracturing*** of oilwell reservoirs;

(5) as a ***refractory agent*** in various types of foundry and molding sands, and for the manufacture of refractory brick.

In addition, silica sand has a number of miscellaneous industrial uses which, together with the processes and products listed above, are described in the succeeding sections of the report.

GLASS SAND

Silica sand is the major raw material for almost all common commercial glasses, comprising 70 to 75 per cent by weight of the furnace batch. Because it forms such a large percentage of the raw materials entering the batch, its chemical quality is of paramount importance. The quality of sand demanded by glass manufacturers depends largely on the type of glass made, e.g., optical, sheet, container, fibreglass, etc. For the better grades of glass the sand must have an extremely high silica content (99 per cent or more) and be essentially free of inclusions, coatings, stains, or accessory detrital heavy minerals. The quality must be guaranteed by the supplier, and uniformity must be maintained.

The most important types of glass in terms of volume and value are the soda-lime-silica glasses. These constitute approximately 95 per cent of the manufactured tonnage. Table 1 lists the raw materials used to make a typical soda-lime-silica glass, the major constituents supplied by these materials, and the resulting chemical composition of the glass. Table 5 gives the composition of some of these glasses.

The criteria for evaluating a sand deposit as a source of glass sand are chemical composition and grain size, which must meet the chemical and physical specifications discussed below.

Table 1. Raw materials used and chemical composition obtained in a soda-lime-silica glass (after Lilge, 1945)

			Glass	
Raw Materials	Per cent of batch by weight	Major Constituents	Chemical Composition	(%)
Sand	64.2	SiO_2	SiO_2	74.7
Feldspar	3.5	SiO_2		
		K_2O	K_2O	0.5
		Al_2O_3	Al_2O_3	0.7
Soda ash	23.8	Na_2O		
Salt cake	0.3	Na_2O	Na_2O	16.1
Borax	1.9	Na_2O		
		B_2O_3	B_2O_3	0.8
Burnt dolomite	6.3	CaO	CaO	4.2
		MgO	MgO	3.0

Chemical Specifications

Silica (SiO_2).

Glass sand requires a high silica content, ideally 99 to 100 per cent SiO_2. Any departure from near absolute purity causes trouble and expense to the glassmaker.

Iron Oxide (Fe_2O_3).

Very small amounts of certain impurities in the sand will lead to tinted or opaque glass. Iron oxide, in the ferric state of oxidation is the most common and most troublesome impurity of this kind, and the glass industry incurs great expense to obtain silica sand sufficiently low in Fe_2O_3. The permissible total iron content, commonly reported as Fe_2O_3 is lowest for optical glass.

As the need for crystal quality diminishes, as in bottles, plate glass, window glass, and finally in amber and green bottles and colored ware, successively larger amounts of total iron (up to 0.20 per cent) are allowed. Sands for making optical glasses generally have less than 0.008 per cent; colorless containers, e.g., milk bottles, less than 0.04 per cent; and window glass, less than 0.15 per cent (Douglas, 1969).

Although various reagents may be used to neutralize color[1] due to iron oxides, manufacturers of high grade glass prefer, if possible, to start with sand of low iron content, because iron is picked up in other ways during the process (e.g. from other raw materials, crucible walls, ladles, etc.). Moreover, the use of neutralizers causes problems in the manufacturing process: for example, in the making of flint glass, if the Fe_2O_3 content exceeds 0.02 to 0.025 per cent, decolorizers must be employed which tend to dull the lustre of the product.

Alumina (Al_2O_3).

Alumina formerly was considered an objectionable impurity in glass sand, but it is now intentionally added to some glass batches. It gives greater chemical durability, lower coefficient of expansion, and greater freedom from devitrification (crystallization of glass). Too much alumina, however, increases the viscosity of the glass, making it difficult to melt and work, and also decreases the transparency of

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[1] In the bottle industry considerable sums of money are spent on decolorizing the glass. The process involves adding arsenous oxide and sodium nitrate to the batch to oxidize the iron, thus minimizing the absorption caused by iron itself, and then adding small amounts of selenium and traces of cobalt to provide a neutral color. Typical additives for decolorizing 1,000 pounds of sand are: 5-8 grams selenium, 0.5-0.8 grams cobalt oxide, 0.5-1 pound arsenic (Douglas, 1969, p. 350). These quantities are interdependent and also depend on the amount of iron and organic material in the sand and on the melting conditions. For example, if the concentration of organic material in the sand is high, extra nitrate is added.

the glass. For the best grade of flint glass, the alumina should not exceed 0.1 per cent, but for some types of amber glass up to 4 per cent may be tolerated.

If alumina is present in the sand, its content should be uniform. The form in which it is present also is of great importance: if the alumina is in the form of clay, it is not readily soluble; if in the form of feldspar, however, it is more easily dissolved. Several glass plants in the United States have adjusted glass batches to accommodate feldspathic sands (Bowdish, 1967).

Lime (CaO).

Sands containing lime in the form of calcite ($CaCO_3$), and dolomite ($CaMg[CO_3]_2$) are to be avoided, for although lime is an important ingredient in many commercial glasses, the calcareous material that is present naturally in sand is generally erratic in its distribution. It is preferable to use lime-free sand and add raw limestone to the batch as required rather than rely on daily analyses for lime content. Lime provides durability of glasses against attack by water and also depresses the melting temperature.

Magnesia (MgO).

Magnesia is generally present in sands in such small quantities that it causes little trouble in glassmaking. An excessive amount (1 per cent or higher) raises the fusion point of the batch, necessitating extra fuel requirements. MgO is added to some glass batches to improve resistance to devitrification.

Titanium Dioxide (TiO_2).

TiO_2 content in glass sand generally should be below 0.03 per cent, for it colors glass and is more difficult to neutralize than iron. However, special glasses high in titanium dioxide are used as glass beads in highway reflective paint because of their high refractive index.

Minor Contaminants.

Most detrital "heavy" minerals[2] in sands are undesirable and must be removed or at least reduced to extremely low levels if the sand is to qualify for glassmaking. Minerals such as magnetite (Fe_3O_4) and ilmenite ($FeTiO_3$) are objectionable because of their iron oxide content. Highly refractory minerals such as the alumina silicates (andalusite, sillimanite, kyanite) and the spinel group (spinel, magnetite, chromite) are detrimental because they survive in the melt, giving rise to unsightly "stones" in the product. The sand should be free of mica, which causes spots and holes in the glass.

[2] "Heavy" minerals are the minor accessory minerals in sands and sandstones that are marked by a relatively high specific gravity (more than 3.0). Common examples are magnetite, ilmenite, zircon, hornblende, garnet, tourmaline, kyanite and rutile.

Secondary mineral coatings and stains on the sand grains also are objectionable; for example, manganese oxide often is associated with trace amounts of cobalt, a powerful blue colorant. As little as 0.0002 per cent cobalt produces a distinct tint in the glass.

One glass manufacturer states in its specifications for glass sand that the weight of heavy minerals of specific gravity greater than 3.0 is not to exceed 0.001 per cent, and also that the weight of coloring oxides other than Fe_2O_3 (e.g., oxides of chromium, manganese, nickel, cobalt, copper) is not to exceed 0.0001 per cent.

Chemical analyses of some typical glass sands used in North America and Europe are given in table 2. The desired chemical specifications for glass sands of major glass manufacturing firms in Canada are given in table 6.

Physical Specifications

Silica sand to be used for glassmaking generally should pass a 20-mesh sieve (0.83 mm) and 95 per cent or more should be retained on a 100-mesh sieve (0.15 mm). Some manufacturers extend the lower limits to 200 mesh (0.07 mm). In the midwest and eastern United States glass producers use silica sand passing a 30-mesh sieve (0.59 mm) with a maximum of 2 per cent passing a 140-mesh sieve (0.1 mm) (Murphy, 1960). West coast glassmakers have adapted to the finer-grained sand native to that region and have extended their tolerance limit of fines[3] to 2 per cent passing a 200-mesh sieve.

Excessive fines in the sand are undesirable because they tend to carry impurities, cause dusting, can be partly lost with the flue gases, and are believed to cause foaming in the tanks. Fines also can contribute to small but persistent seeds or blisters in the glass. On the other hand, excessively coarse grains often survive in the melt and cause the formation of harmful batch scum, stones,[4] and cords.[5] Coarse sand also is more difficult to fuse and tends to decrease the daily throughput of each furnace.

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[3] Fines — a particle-size classification of nonmetallic materials in a sand mixture with diameters less than 0.074 mm (200 mesh).

[4] Stones — non-glassy material imbedded in a piece of glass. For example, if sand is too coarse some of the quartz grains may escape solution.

[5] Cords — striae, threads or local concentrations of oxides which produce a refraction differing from the refraction of the main body of the glass.

Table 2. Chemical analyses of some typical glass sands

Locality	Chemical Constituents (%)								Reference
	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I.	
Ottawa, Illinois	99.61	0.02	0.16	0.05	0.03	-	-	0.08	Cole, 1923
Valley, Washington	99.60	0.03	0.29	-	-	0.02	0.05	0.04	Pers. comm.
Selkirk, Manitoba	99.70	<0.06	0.10	tr	tr	tr	tr	-	Pers. comm.
Norfolk, England	99.25	0.04	0.59	0.11	0.03	-	-	0.25	Cole, 1923
Fontainebleau, France	99.80	0.006	0.13	tr	-	-	-	0.18	Cole, 1923
Belgium	99.12	0.07	0.43	0.34	0.11	-	-	0.22	Cole, 1923

Grain size analyses of some glass sands used in the United States and Canada are given in table 3. The desired size specifications of some Canadian glass manufacturers for glass sands are given in table 7.

Glass Industry In Alberta

The major manufacturers of glass and glass products in Alberta at the present time are Dominion Glass Company Limited at Redcliff, Fiberglas Canada Limited at Edmonton, and Canadian Johns-Manville Co., Limited at Fort Saskatchewan. Several other companies operate small glass plants mainly for manufacturing handmade ornaments, but their consumption of silica sand is small compared with the three major consumers. The bulk of the sand used in the glass industry currently is imported from outside Alberta; however, increasing usage of local dune sand sources is foreseen.

Dominion Glass Company manufactures machine-made containers at its Redcliff plant using silica sand currently supplied from Selkirk, Manitoba (Tables 2 and 3). The company's specifications as of 1969 for glass sand are given as follows:

Chemical Analysis

	Flint Quality Glass	Colored Glass
SiO_2	99± 0.4% Consistent Balance	99±0.4%
Al_2O_3	0.05	0.05
CaO	0.15	0.15
MgO	0.10	0.10
Na_2O	0.02	0.02
K_2O	0.03	0.03
Fe_2O_3	0.042[1] max.	0.15 max.
Cr_2O_3	0.0003 max.	0.0050 max.
TiO_2	0.05 max.	0.10 max.
Organic	0.05 max.	0.10 max.
Moisture	0.10 max.	0.10 max.

[1] Provided Fe_2O_3 in limestone is < 0.060 and blast furnace slag is not used.

Table 3. Grain size analyses of some typical glass sands (cumulative weight per cent retained)

U.S. Standard Sieve No.	Opening (mm)	Locality					
		Ottawa, Illinois [1]	Valley, Washington [2]	Selkirk, Manitoba [2]	Mapleton, Pennsylvania [1]	Wedron, Illinois [1]	Crystal City, Missouri [1]
20	0.84	-	-	-	0.10	-	-
30	0.60	0.10	4.75	-	3.30	0.70	0.10
40	0.42	19.50	23.25	7.50	20.30	11.60	2.90
50	0.30	60.00	51.75	-	62.90	42.10	23.10
60	0.25	-	-	65.50	-	-	-
70	0.21	85.70	77.75	-	90.30	74.30	51.30
80	0.18	-	-	94.50	-	-	-
100	0.15	98.00	91.75	98.00	97.50	94.60	77.10
140	0.10	-	97.25	-	-	99.30	90.60

[1] after Ries, 1949
[2] pers. comm.

Grain Size Analysis

U.S. Standard Sieve No.	Opening (mm)	Per Cent Retained
> 20	0.80	0.2
20-30	0.80-0.60	4.8
30-40	0.60-0.42	25.0
40-100	0.42-0.15	57.0
100-140	0.15-0.10	8.0
140-200	0.10-0.07	3.5
< 200	0.07	1.5

Canadian Johns-Manville Co., Limited and Fiberglas Canada Limited operate plants in the Edmonton area for the production of glass fibre products and fibreglass insulation. Canadian Johns-Manville currently obtains sand from Selkirk, Manitoba (Table 2) in mesh size 20-100 to meet its specifications. Fiberglas Canada has in the past obtained all its sand requirements from Valley, Washington (Table 2), with a grain size distribution as follows:

U.S. Standard Sieve No.	Opening (mm)	Per Cent Retained
>50	0.30	2.25
50-70	0.30-0.21	35.50
70-100	0.21-0.15	29.00
100-140	0.15-0.10	20.00
140-200	0.10-0.07	7.50
<200	0.07	5.75

Recently the company has been able to replace some of the Washington sand with a local dune sand.

As a rule the requirements in fibreglass production are for a finer-grained sand than is commonly used for other glass products. The use of a fine sand increases melting efficiency for the type of furnaces used; some fibreglass plants, owing to the nature of their particular product, specify a fineness which is met only by pulverized sand.

ABRASIVE SAND

Sandblasting Sand

Silica sand as a scouring agent is effective for such uses as cleaning metal castings; removing paint, rust, and scale; cleaning tanks and pipelines; renovating walls of stone or brick; etching glass and plastics; and engraving on stone or marble. The sand is carried under pressure by air, water, or controlled centrifugal force, and can be used repeatedly until the grains become too fine. The resulting dust and fine sandy material can be blasted wet (mudblasting) to produce a dull finish.

Many factors are to be taken into account in choosing a sand for sandblasting, such as amount of sand loss, the angularity and toughness[6] of the grains, the amount of work done per pound of sand used, the texture of the surface required on the finished article, and the grain size of the sand. However, the cutting power of the sand is the most important quality. It is only by subjecting a sand to an actual sandblasting test that a measure of its suitability can be made.

Specifications

Sandblasting sand should be clean and free of adhering clay or coatings of iron oxide. Material that dusts upon handling cannot be tolerated. The sand should have a fairly high quartz content (sands containing from 78 to 99 per cent SiO_2 have been used), so that little waste results from the presence of minerals too soft to be effective.[7]

Both rounded and angular sand grains are used in sandblasting work. Rounded grains are more commonly used, for they produce smoother surfaces and are more durable (i.e., less loss in fines). The peening action of rounded grains is desirable for achieving a satin finish for certain light metal castings. However,

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[6] All quartz grains have about the same hardness, but vary considerably in toughness, i.e., ability to resist crushing and shattering. For pipeline cleaning some sandblasting firms prefer sand particles which shatter on initial impact and thus provide many finer, highly angular fragments. These remain suspended in the air stream and provide good scouring action as they are forced through the pipeline.

[7] Garnet sands also are used for sandblasting. Garnet (iron-magnesium-aluminum silicate) is almost as hard as quartz but much denser (s. g. 3.2-4.3), therefore delivering a harder blow than quartz grains. Garnet is concentrated locally in certain river and lake sands in Alberta; however, these sands would require extensive beneficiation to separate the garnet from other minerals.

angular grains have faster cutting power and are preferable under certain conditions. The physical and mineralogical properties of some sandblasting sands used in Canada are given in table 8.

Most sandblasting sands are sold in grades based on screen-mesh size. These grades commonly are numbered 1 to 4 denoting fine to coarse, although the grade sizes may vary throughout the country depending on the variation in predominant grain size of sands in different areas. The size standards adopted by the U.S. Bureau of Mines are given below:

U.S. Standard Sieve No.	Opening (mm)	Grade Size
20-40	0.84-0.42	1
10-30	2.00-0.59	2
6-12	3.33-2.00	3
4-8	4.70-2.36	4

Grade No. 1 is useful for light work where a smooth finish is desired, such as automobile castings, finishing brass, frosting glass, and removing paint, Grade No. 4 is suitable for rough cast iron and cast steel work.

Blasting Sands Used in Alberta

Much of the Alberta lake, outwash, or dune sands are suitable, after washing and sizing, to meet the specifications for the finer grades of blasting sand. However, material coarser than 20- to 30-mesh is very scarce in the province, and must be imported or obtained as screenings from gravel crushing operations. The sand from oil-sand tailings at Fort McMurray is very fine; hence its use for sandblasting is even more restricted than other known deposits of sands in Alberta. Table 9 gives some of the common uses of blasting sands in Alberta, the grain size specified, and the source of the sand.

Minor Uses of Abrasive Sands

The following uses of silica sand have little application in Alberta at the present time but could become important in the future.

Banding Sand

Banding sand is a silica sand used for the grinding of tool handles, as an abrasive in beveling glass, and to some extent for the second or semifinal grinding of plate glass. However, it has been largely superseded by artificial abrasives which cut more rapidly.

Banding sand is a much finer sand than that used for the initial grinding of plate glass. A screen analysis of a typical banding sand from an Illinois supplier is given below:

U.S. Standard Sieve No.	Opening (mm)	Per Cent Retained
> 40	0.42	1
40-50	0.42-0.30	3
50-70	0.30-0.21	33
70-100	0.21-0.15	37
100-140	0.15-0.10	20
140-200	0.10-0.07	6

Glassgrinding Sand

In the "flat glass production" method for making plate glass, the crude-rolled plate requires rough grinding to remove gross surface inequalities before final grinding and polishing. Quartz sand is almost universally used for this purpose. Garnet and artificial abrasives are used to some extent, mostly in the semifinal grinding stage. The sand, in a water slurry, is fed to successive grinding heads in progressively finer grades. The water serves as a distributing medium, prevents overheating of the glass, and increases the grinding rate. Two to three tons of sand are required to polish one ton of plate glass.

Most glass companies use the same sand for grinding as for the glass mix. Generally, the sand is graded at the plant into several sizes for use in progressively finer grades. The use of glass sands high in quartz assures little waste resulting from the presence of minerals too soft to be effective. Glass sand producers market a product for glassgrinding, the constituent grains of which all pass 20 mesh. One large glass manufacturer uses a sand composed of distinctly rounded grains that will pass 20 mesh, about 90 per cent being retained on 150 mesh.

In the newly developed "float process" for the manufacture of sheet and plate glass, the need for grinding and polishing is eliminated.

Sandpaper

Although at one time natural sand was the abrasive base in sandpaper, crushed and closely graded quartz or garnet is now mainly used. The grains of some natural sands are more or less angular or "sharp," but they do not have the sharp cutting edges of grains broken down from larger fragments. It is these sharp edges which are especially desirable in woodworking.

The rapid development of artificial abrasives such as silicon carbide (SiC) and fused aluminum oxide with their superior hardness, sharpness, and tougher grain together with improvements in methods of recovery and preparation of garnet have resulted in substantial displacement of quartz as a coating in sandpaper.

Scouring Sand

Silica sand, in both pulverized and natural states, is used for abrasive purposes in hand soaps, kitchen cleansers, buffing compounds, scouring compounds, tooth powders and pastes, and metal polishes. Chemically, the sand should not contain more than 0.05 per cent iron oxide (Fe_2O_3).

For natural sand grains used in scouring compounds, United States federal government specifications require that the grains included in grit cake soap and scouring compounds shall all pass a No. 100 screen. Grains for scouring compounds for marble floors must all pass a No. 100 screen, 95 per cent must pass a No. 200 screen. For ceramic floors 90 per cent must pass a No. 80 screen and 95 per cent a No. 60 screen.

In the production of silica flour or pulverized sand, quartz sands are commonly dry-ground and then air-separated, with the ground product falling into three general mesh sizes of -140, -200, and -325. Very fine air-floated quartz is employed in metal polishes, and all grains must pass a 325 mesh screen.

Stonegrinding and Marblegrinding Sand

Abrasive sand for rough grinding of stone and marble is generally of the same grade as that used for stonesawing. Different stones and types of finish require different grades of sand. Grains of relatively coarse sizes are used. Some consumers claim faster cutting with sharp, angular grains, although with repeated use the sand grains quickly become worn. A good grade of silica sand with hard, tough grains which will not readily break down is the best. An excessive amount of silt and clay reduces the efficiency.

Stonesawing Sand

Sand is used in the process of stonesawing to support the cutting edge of the saw blade. Commonly, the main requirements for such sand are a high percentage of quartz, and low amounts of clay, mica and soft rock fragments. Flat particles are objectionable and fines are wasted, for only the coarser grains support the cutting edge. Both rounded and angular grains are used in stonesawing.

Neither textural nor chemical specifications are rigorous for stonesawing sand. River and glacial sands which have been washed and screened to remove oversized and fine particles are commonly used as they are cheap and available. One large marble company uses washed river sand with the following range of sizes (after Weigel, 1927):

U.S. Standard Sieve No.	Opening (mm)	Cumulative Per Cent Retained
12	1.70	3.7
20	0.80	12.6
50	0.30	83.8
100	0.15	98.6

Some plants prefer to use a graded sand about equal to a No. 1 sandblasting sand (Sandblasting Sand, p. 12). The following is a typical sieve analysis of sawing sand marketed by an Illinois supplier:

U.S. Standard Sieve No.	Opening (mm)	Per Cent Retained
>30	0.60	5
30-40	0.60-0.42	74
40-50	0.42-0.30	20
50-70	0.30-0.21	1

In addition to silica sand, sands composed of garnet and silicon carbide also are used for stonesawing.

HYDRAULIC FRACTURING SAND

Special grades of high quality silica sand are used by oilwell servicing companies for hydraulic fracturing of oil-bearing formations where the reservoir rocks are of such low permeability that they are capable of only small rates of production. In such cases production may be stimulated by resorting to hydraulic fracturing.

In the hydraulic fracturing process fluid pressure is applied to the reservoir rock until fracturing occurs. After failure of the reservoir rock, a sustained application of fluid pressure extends the fracture outwards from the point of failure in the borehole wall, creating new and larger flow channels. Selected grades of "propping agents" are then added to the fracturing fluid in varying quantities. The fluid, or "carrying" agent, may be an emulsion, an aqueous or kerosene gel, viscous crude or refined oil, thickened acids, or fresh or salt water. The propping agents act as supports to hold the fractures open after the carrying agent is removed. Sand has been used almost universally for this purpose; an average application is 4 to 5 tons of sand per well, although as much as 125 tons has been used.

Chemical Specifications

For effective use in formation fracturing, the sand must be high in silica, which is chemically inert in fracturing and reservoir fluids. It must have a solubility of less than 5 per cent in hydrochloric and drilling-mud acids and preferably contain no carbonates, aluminosilicates or other oxides. The sand should also be free of clay, silt, or organic matter which would adversely affect the viscosity of the carrier or cause dusting in handling, or both.

Physical Specifications

The preferred textural properties of hydraulic fracturing sands are given in table 10. Spherical particles are preferred over angular grains of equal size because they allow greater permeability when packed. Angular grains are more difficult to place in formations; the sharp corners have a tendency to lodge against obstructions and interlock, thus restricting the free rolling action within a fracture exhibited by rounded grains. This leads to a bridging action in the hole, in the subsurface tools, and in the fracture. Generally, sand for use in hydraulic fracturing should have a roundness[8] factor of 0.6 or more.

Grains must be structurally sound to be able to withstand overburden pressures at depths of 10,000 feet or more. They should have a minimum compressive strength of 2,500 psi and a maximum particle density of 2.7 (Murphy, 1960). Grain size should be uniform; poorly sorted grains lead to lower permeability, consequently, sand used for hydraulic fracturing is generally graded. The grade most used is the 20-40 U.S. Standard Sieve size range. Several other grades are used when a "step" process of fracturing is employed, i.e., when successively coarser grades of sand are forced into the formation (8-12, 10-20), terminating with a subrounded sand to bridge the fracture opening and prevent backflow of the initial charge of well-rounded sand. Finer sand, such as 40-60 mesh,

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[8] The degree of roundness has been defined by Pettijohn (1949, p. 49) as the ratio of the average radius of curvatures of the several corners or edges to the radius of the largest inscribed circle on the projected image of the sand grain.

has found application in some wells where fracture width is sufficiently narrow to cause sand bridging.

Typical physical and chemical characteristics of various grades of hydraulic fracturing sand used in Alberta are shown in table 11. One oil company operating in Alberta gives the following specifications for sand used in its wells.

Particle-size distribution: all fracture sand must contain at least 80 per cent of its particular mesh range.

Roundness: a roundness factor of greater than 0.7 is required.

Strength: the minimum acceptable strength of the average propping agent shall not be less than 25 pounds per particle. Preferably, the propping material should have strengths of greater than 200 pounds per particle.

Specific gravity: specific gravity is an indication of the ease with which the propping agent may be transported by the fracturing fluid. A specific gravity of more than 2.7 is not acceptable.

The propping agent should not be affected by hydrochloric acid, should not be oil soluble, and should not possess over 1 per cent silt or foreign material.

Alberta Market

In 1961 the consumption of fracturing sand in Alberta was estimated by users and suppliers at 15,000 tons. By 1968 it had declined to an estimated 5,700 tons. The sharp decrease in consumption is due to: low level of production drilling in sandstone formations; and other products, such as glass beads, walnut shells, and aluminum pellets being used as substitutes for silica sand.

Most of the fracturing sand currently used in Alberta is imported from Texas and Minnesota.

BUILDING PRODUCTS SAND

Silica sand is used in the manufacture of a variety of building products. In general, specifications for such sand are less rigorous than those associated with glass manufacture and certain other products. Hence, local sources of sand such as dune and glacial outwash deposits, common in many parts of Alberta, merit some consideration for use in the products described below.

Asbestos Cement Pipe (Transit Pipe)

Transit pipe is made from a mixture of asbestos fibres, silica sand, and cement. Quartz sand used in the manufacture of steam-cured asbestos cement products must be high in free silica. Specifications given by Canadian Johns-Manville Co., Limited, manufacturers of asbestos cement pipe, are as follows:

Chemical Analysis

Constituent	Composition (%)
Free Silica (SiO_2)	96.0 min.
Iron oxide (Fe_2O_3)	1.0 max.
Alumina (Al_2O_3)	0.5 max.
Lime and magnesia ($CaO + MgO$)	1.5 max.
Soda and potassium ($Na_2O + K_2O$)	1.0 max.

Grain Size

U.S. Standard Sieve No.	Opening (mm)	Per Cent Passing
60	0.25	100
80	0.18	99
100	0.15	90
200	0.07	85

Sand having a high total silica content will be acceptable if the silica bound in hornblende, feldspar, or other mineral impurities does not lower the free silica content below 96 per cent. Soda and potash are detrimental as they provide a residual alkali when used for electrical cable ducts.

Asphalt Roofing Tile

Silica sand for use in asphalt roofing tile must be high in silica, free of clay and organic impurities, white in color, with grain size between 20 and 100 mesh.

One manufacturer uses a fine white sand of the following size:

U.S. Standard Sieve No.	Opening (mm)	Per Cent Retained
>40	0.42	1.5
40-60	0.42-0.25	72.5
60-80	0.25-0.18	89.0
<80	0.18	11.0

Domtar Construction Materials Ltd. at Lloydminster, Alberta, utilizes local dune sand graded to 60-72 mesh size.

Sand-Lime Brick

Sand-lime brick is a white standard-size brick used for ornamental purposes in facing private dwellings and small buildings. It is composed of silica sand (80-85%) and lime, which react under heat and pressure to form a calcium silicate bond. For this purpose a certain amount of extremely fine material (silica flour) must be present, for the action of lime on larger grains under the temperatures and pressures normally applied is quite slow. At least 10 per cent of the sand should pass a 140 mesh sieve, and all passing 20 mesh sieve. The sand may contain 2 per cent clay but not more than 5 per cent. It should be angular, reasonably clean, and free from organic matter. Extreme chemical purity is not essential, but the most attractive brick is provided by white sand free from dark-colored grains.

Sand-lime bricks have been manufactured in Alberta by Medicine Hat Brick and Tile Company, Limited at Calgary. Local sand from dune deposits east of Calgary were used for most of the requirements; small quantities were imported from Selkirk, Manitoba and Oliver, British Columbia.

REFRACTORY SAND

The heat-resistant nature of quartz (melting point = 1710° C [3110° F]) makes silica sand an excellent refractory substance for a number of industrial processes and products. In this capacity, the sand can be used directly as it is found (natural-bonded sand), in a beneficiated or treated state (synthetic-bonded sand) or for the manufacture of silica brick. The more common uses of refractory sand and their specifications are described below.

Foundry (Molding) Sand

Large tonnages of silica sand are used in iron and steel foundries to make molds and cores for metal castings. Molten metal is poured into a shaped cavity in a block of sand where the metal cools and solidifies. The part of the cavity that forms the external surface of the castings is called the mold. Cores of molded sand may be placed in the mold to form the internal shape and dimensions of the casting. In each application the sand particles are held together by some material called a bond. From 4 to 5 tons of sand are prepared and handled per ton of metal poured.

Two types of molding sands are distinguished on the basis of the bonding agent. Naturally bonded molding sands are those with a natural content of clay and silt sufficient to give plasticity and strength to the sand when tempered with water. The clay content generally limits the use of these sands to light iron, brass, or bronze castings.

Synthetically bonded sands are artificial mixtures of clean silica sand and a bonding agent such as fireclay or bentonite. Sand with little or no natural bond generally is more refractory than naturally bonded sands and is used in steel foundries, magnesium foundries, and in large grey-iron and malleable-iron foundries where extremely high temperatures are obtained.

The trend today is toward increasing use of synthetically bonded sand, for it can be controlled to offer molding properties that are dependably uniform. Uniformity becomes increasingly important as foundries become more and more mechanized.

General Requirements of Molding Sands

The ideal molding sand has been described as "a sand consisting of uniform-sized rounded grains of silica (quartz), each grain evenly coated with the thinnest necessary layer of the most refractory and fattest clay" (Moldenke, 1930, p. 334). A foundry mold must have the ability to withstand the high temperature of molten metal without damage to the surfaces of contact between metal and sand. The required heat resistance varies with the type of metal being cast. For example, steel which melts at about 1510° C (2750° F) requires a much more refractory sand than aluminum alloys which melt at about 650° C (1200° F). Silica sand used for steel casting must consist entirely of quartz grains to be infusible. The coating of clay that binds the grains together must be sufficiently low in fluxing ingredients to resist softening or change of shape at least until the metal is fully set. Large castings require a more highly refractory sand than small castings, because of the longer cooling period and the sustained heat to which the sand is exposed.

Another important requirement is that the finished mold be strong enough to withstand the pressure of the molten metal without yielding. The sand must be adhesive, containing sufficient clay bond to remain intact after being rammed into place about the pattern. On the other hand, the mold must be sufficiently permeable to allow the steam generated on contact of the molten metal with the damp mold surfaces to dissipate quickly. This steam should pass outward through the mold and not through the molten metal. Furthermore, any gases carried in the metal and liberated at the moment of set must be able to pass through the sand. To satisfy these conditions, a molding sand must have the proper grain size and shape relationship.

The mold should leave the casting with a smooth surface. The coarser the grains of silica, the rougher the surface of the casting; however, fine-grained sands do not provide the best venting qualities. A compromise must be made in the selection of a sand.

The quality of castings produced depends largely upon the properties of the sand utilized. To ensure good castings, the sand must satisfy specifications as to (1) refractoriness, (2) bond strength, (3) permeability, (4) grain fineness, and (5) moisture, as discussed below. The properties of typical molding sands used for various types of castings are given in table 12.

(1) Refractoriness. Quartz (SiO_2), the principal constituent of silica sand, is a highly refractory mineral, the fusion point of which is 1710° C (3110° F), well above the pouring temperature for either iron or steel castings. The alkali-bearing minerals are more readily fusible; feldspars, for example, melt at a temperature between 1200° C (2190° F) and 1300° C (2370° F). Thus, if metal is poured into a mold at a temperature higher than 1300° C (2370° F), any feldspar grains present may fuse and permit entry of metal into the mold. Fusion also is encouraged by the presence of micas and iron oxides; consequently, the content of these impurities must be carefully regulated. Lime, soda, and magnesia act as fluxes to reduce the refractoriness of the sand and should be present in only trace amounts, the average permissible content of the three constituents combined being about 2 per cent. Chemical analyses of some foundry sands in common use are given in table 13.

The fine-grained silty or clayey bonding material of a molding sand is most susceptible to destruction from sustained heat, for it contains the least refractory and most active fluxing constituents. Thus, for steel casting synthetic sand is generally prepared by adding fireclay as a bond to grains of almost pure quartz (more than 98 per cent SiO_2). However, for metals such as aluminum or brass, naturally bonded sands containing feldspars or other low-melting constituents are satisfactory.

Refractoriness is also influenced by grain size, which determines the surface area of the quartz grains exposed to the action of heat and fluxing ingredients. The finer the quartz grains, the more readily are they attacked. For this reason much high-temperature fine casting is now done using olivine

($[Mg,Fe]_2SiO_4$), zircon ($ZrSiO_4$), or chromite ($[Mg,Fe]CO_2O_4$) sands because of the superior refractoriness of these minerals over quartz.

(2) Bond Strength. Bond strength of a molding sand depends primarily on the nature of the bonding clay. Kaolinite (such as china clay) gives low to medium bond strength, illite gives medium bond strength, and montmorillonite the highest bond strength. Sodium montmorillonite clays (such as some bentonites) will give nearly double the dry strength of calcium montmorillonite clays; on the other hand, the wet (green) strength of sand with calcium montmorillonite is higher. Although it is desirable to have fairly high green strength (and this is usually a test for the ability of a foundry sand to obtain good "lifts"), sands with very high green strength are hard to ram and may result in swollen castings (Parkes, 1950, p. 12). Bond strength generally is measured and expressed as "green shear strength" and "green compression" in pounds per square inch (Table 14).

Grain shape also contributes to bond strength of a sand. As a rule, the finer and more angular the sand grains, the greater the bond strength of the sand because of the interlocking of grains. However, permeability is decreased, so that in most cases it is better to depend on the bonding material for cohesiveness.

(3) Permeability. The best permeability is obtained with molding sand in which the grains are both rounded and uniform. Angular-grained sand tends to pack and makes permeability control difficult. Furthermore, if the grains are not of uniform size, small grains may pack between large ones whether they are angular or round, decreasing the porosity and thus impairing the permeability.

The permeability of molding sands is expressed as an AFS[9] permeability number, which refers to the volume of air per minute, under a given pressure, passing through a unit volume of sand.

Finer sands have a lower permeability number because of the smaller and more complex pore systems. Air and gas will pass more easily through large pores, so that, generally, the coarser the sand the higher the permeability (Table 14). On the other hand, the surface finish of a casting is impaired by large pores. Therefore, the selection of a sand usually is a compromise between the desirable venting ability and the surface finish required.

Despite the fact that the highest permeability can be obtained by using a uniformly sized sand, in practice a range of five or six sieve sizes of sand is used to prevent all the grains from reaching the temperature of 573° C[10] at the same time during casting. At this temperature silica undergoes a sudden change in volume, and

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[9] American Foundrymen's Society.

[10] The critical temperature for a crystallographic transformation in the mineral quartz, from low temperature α-quartz to high temperature β-quartz.

if all the grains were to expand at the same time serious "scabbing" may occur at the top of large mold cavities (Parkes, 1950, p. 9).

Any excess of clay or other bonding material will tend to fill the voids and reduce permeability. The clay content should be sufficient to coat the sand grains but not so much as to clog the pores.

(4) Grain Fineness. Grain size or fineness has an important bearing on the physical properties of foundry sand as noted in the foregoing discussion and also in table 12, which shows variation in properties with texture over a range of size grades of sand. Fineness also is important because of its relationship to the surface finish of castings. The finer the grains, the smoother the work produced, whereas coarse grains in the mold surface allow penetration of metal between grains, thus leaving a rough surface. The highest grade of art castings is made with the finest molding sand. Brass and bronze require fine sands. On heavy castings a fine-grained facing sand is used to give a smooth surface.

On the other hand, the finer the sand, the poorer the venting. Therefore, the selection of a molding sand is for the finest grain size possible that still allows safe venting of the molds.

To the foundryman, the fineness of foundry sand is a prime indicator of quality and is expressed in terms of a grain fineness number (GFN), which represents approximately the sieve size (in meshes per inch) that would just pass a sand sample if all its grains were of equal size to the weighted average grain size. The GFN is determined in a standard AFS fineness test, which tells the foundryman not only the size of the sand grains and proportions of each size, but also the proportion of clay in the sand (expressed as AFS clay).

AFS clay by definition consists of mineral particles of less than 20 microns diameter, essentially a mixture of clay minerals and fine (quartz) silt. Its determination in the fineness test is by a standard method based on the settling velocities of different particle sizes in a suspension. The GFN is determined by removing AFS clay from a weighed amount of sand, subjecting the sand fraction to standard sieve analysis, and multiplying the percentage of sand retained on each sieve by a factor for that sieve size. The products of the multiplications are then added, and the total divided by the sum of the percentages retained on each sieve. The resulting number is the GFN.

Many foundries use GFN and the percentage AFS clay as the basis for specifying the sand required from producers to maintain uniform properties of sand in the foundry. The GFN by itself does not give much information on the size distribution of grains in the sand, but it is a convenient means of expressing the average grain size. Sieve analyses and corresponding GFN's are given in table 15 for a variety of foundry sands in common use.

(5) Moisture. The ideal amount of moisture in a molding sand is that just sufficient to yield the necessary plasticity and adhesiveness in order that molding operations can be performed properly without excessive ramming or defective molds. Excess moisture results in the formation of large volumes of steam, which cannot be vented adequately through the sand. Entrapped steam thus produces cavities in the casting.

Special Molding Sands

Silica sand has the disadvantage of being chemically reactive at the high casting temperature of many metals, at which point it may fuse to form silicate minerals. It also undergoes a large and rapid volume change on heating when passing the critical temperature of 573° C (see footnote, p.23).

In preference to silica sand, olivine, zircon, and chromite sands are finding increasing use as mold materials for high-temperature castings. Olivine is a natural mineral consisting of variable proportions of forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4) in solid solution, and only olivine with the highest forsterite content is sufficiently refractory to be useful as foundry material. Forsterite melts at 1890° C (3434° F), fayalite at 1205° C (2201° F). Olivine is used extensively in the production of austenitic manganese (stainless) steel, because it is not attacked by manganese oxide slags.

Zircon sand is composed of grains of almost pure zirconium silicate ($ZrSiO_4$). This material is favorable because of its commonly fine, uniform grain size, high melting points – from 2010° C (3650° F) to 2120° C (3850° F) – and low thermal expansion. Moreover, zircon sand is 70 per cent heavier than silica sand and has a higher heat conductivity that gives more rapid chilling of castings. Its nonwetting characteristics make it especially useful for cores.

Chromite ($[Mg,Fe]Cr_2O_4$) is effective in casting manganese steel. It has a much lower linear expansion value than silica sand but slightly higher than zircon sand. It has very good chilling properties and can be produced in a wide range of AFS grain fineness numbers. Being basic in nature, it does not combine chemically to form reaction products with molten metal. It has been found to be more resistant to metal penetration than either silica or zircon.

In addition to the technical disadvantages associated with quartz molding sands, the health hazard of free silica has been recognized by medical authorities in connection with a variety of lung diseases. For this reason, in Sweden olivine sands have displaced silica sand for all types of castings, and in Great Britain every effort is being made to convert to molding media such as zircon, chromite, and olivine.

Alberta Market

In 1968 approximately 3,150 tons of foundry sands were used in Alberta, including quartz, zircon, and olivine sands, with a value of $46,700. Most of this sand was imported. Table 16 gives a list of foundries in Alberta, the sand they use, and the source of this sand. Detailed specifications for two of these foundries are given in table 17.

Core Sand

Core sand has similar properties to molding sand but is coarser grained and always requires a bond that will bake at the temperature of pouring but will break down easily. Bonding material may consist of linseed oil, cereal flour, resin or some other material that "sets" when it is baked.

The sand should be high in silica and low in alumina. Well-rounded grains provide the best venting power, but with oil sand cores in which a very small amount of binder is used, angular grains provide better bonding power.

Core sands of three or four sieve sizes in the AFS grain fineness range of 45-55 are marketed for iron and steel work. Generally, the most satisfactory particle size distribution is from 30 to 140 mesh with 90 per cent or more lying between 40 and 100 mesh. Table 18 gives grain size analyses of some widely used core sands.

Fire (Furnace) Sand

Fire or furnace sand is used to line furnace bottoms, walls in open-hearth furnaces, cupolas and ladles. It also is used largely in forming the bottoms of copper-refining furnaces and reverberatory copper-smelting furnaces.

A high quartz content (more than 95 per cent SiO_2) is essential to obtain the necessary refractory properties, and a small amount of bonding material is required to hold the sand in place until the furnace lining has been fired or burned in. If the sand lacks bond, the latter is usually added in the form of plastic fireclay. However, many furnace sands have enough natural bond and are often more desirable than artificially bonded material. As in molding sand, this natural bond is usually clay or iron oxide. The proportion of alkaline constituents should be minimal. Following are the chemical properties of a furnace sand from Massillon, Ohio (Weigel, 1927):

Constituent	Composition (%)
Silica (SiO_2)	97.27
Alumina (Al_2O_3)	0.80
Iron oxide (Fe_2O_3)	0.52
Other oxides	0.75

A product graded from coarse to fine is usually considered better than one of uniformly sized grains, as the fines assist in bonding, fill voids between the larger grains, and make the hearth more impervious. Moreover, the finer grains sinter more rapidly during firing in a new bottom. Table 19 gives grain-size data for three typical furnace sands.

In some cases the spent molding sand is used as furnace sand for the bottoms of open-hearth steel furnaces. The spent sand is said to give better service than new sand owing to the increase in fines from the clay bond added for molding.

Potter's Sand

This material is used in the ceramic industry by manufacturers of white ware, wall and floor tile, heavy clay products, and refractories as a packing in the saggars and between the shapes to keep the ware apart. It is of two general types; that used for white ware and refractories (which must be low in iron [less than 0.3] and in easily fusible or fluxing minerals) and that for dark, heavy clay ware which need not have such high purity. There are two general grades, coarse and fine, the coarse being sand between 10 and 40 mesh and the fine between 28 and 100 mesh. A good grade of glass sand is suitable for most work. Extreme uniformity of grain is not essential, but coarse particles and dust are objectionable (Weigel, 1924).

Silica (Refractory) Brick

Silica bricks are made from silica sand or crushed quartzite with lime added to develop bond. Their most useful property is the ability to support loads at high temperatures. They are used for roofs of basic open-hearth steel furnaces, lining parts of coke ovens, reverberatory furnaces, roofs of glass melting tanks, and many other types of furnaces. The raw material should contain between 96 and 98 per cent SiO_2, less than 1 per cent Al_2O_3 (combined iron and alumina under 1.5 per cent), and alkalies less than 0.3 per cent. The following is a typical analysis of a quartzite mix used in the manufacture of super duty silica brick (Ver Planck, 1966, p. 40):

Constituent	Composition (%)
Silica (SiO_2)	96.40
Alumina (Al_2O_3)	0.15
Iron oxide (Fe_2O_3)	0.59
Titanium dioxide (TiO_2)	0.04
Lime (CaO)	2.49
Magnesia (MgO)	0.08
Soda (Na_2O)	0.12
Ignition loss	0.02

A suitable grain-size distribution usually has about 55 per cent retained between 4 and 30 mesh, 20 per cent retained between 30 and 70 mesh, and 25 per cent less than 70 mesh.

Semi-silica bricks have 78 to 93 per cent silica as against more than 96 per cent in true silica bricks, the remainder of the mix being fireclay. They are used in open-hearth furnace checker settings.

Silica sand also is used in the manufacture of sand-lime brick (p.20) and as an additive in common brick to increase refractoriness.

MISCELLANEOUS SAND USES

Chemical Sand

The chemical industry uses silica sand in the manufacture of such products as sodium silicate, silica gel, silicon carbide, silicon tetrachloride, and a wide variety of silicones. The sand must be of a purity similar to that used for glassmaking, i.e., 99.0 to 99.5 per cent SiO_2. Permissible trace impurities vary according to use; for example, discoloration due to excessive amounts of iron and titania is important to sodium silicate producers, but is not as critical in silicon carbide manufacture.

Sodium silicate (water glass = hydrous sodium silicates) is made by fusing silica sand with either sodium carbonate, or sodium sulphate and a reducing agent such as carbon, at about 1200-1400° C for about eight hours. A good quality silica sand for the manufacture of sodium silicate should contain approximately 99 per cent SiO_2, with not more than 1 per cent Al_2O_3,[11] 0.5 per cent CaO+MgO, and 0.1 per cent iron. All the sand normally should pass a 20-mesh sieve and be retained on 100 mesh.

Silica gel is made by reacting sodium silicate with an acid, and drying and granulating the resultant gelatinous silica to form an extremely porous, hard, absorbent solid. The substance is used for many industrial processes involving dehydration and absorption.

Silicon carbide, an artificial abrasive, is manufactured in electric-resistance furnaces by the reaction of silica and carbon at a temperature above 1,500° C. Sawdust and salt are added to the charge, sawdust to promote porosity for the circulation of hot vapors, and salt to react with iron and other impurities to produce volatile chlorides. The reduced product is cleaned, crushed, and ground. Sand used for

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[11] Alumina reduces the solubility of the resulting silicate.

silicon-carbide manufacture should have a silica content of 99.0 to 99.5 per cent. Iron (Fe_2O_3) and alumina (Al_2O_3) should be less than 0.1 per cent each. Lime, magnesia and phosphorus are objectionable impurities. A coarse-grained sand is preferred; all sand should be +100 mesh, with the bulk of it +35 mesh (Collings, 1968).

Silicon tetrachloride is manufactured from silica sand and sodium chloride. It is used with organic chlorides and other organic compounds to make silicones – compounds of silicon and oxygen that have hydrocarbon groups bound directlv to silicon atoms. Silicones are used for their resistance to high temperatures in varnish, for electrical insulation and in high temperature-resistant greases.

The market for chemical sand in Alberta is very small, and all the requirements currently are imported.

Coalwashing Sand

Coalwashing sand is a washed and graded silica of constant specific gravity used in the Chance sand-flotation process for cleaning anthracite and bituminous coal. In the Chance process the separation of coal from impurities is effected in a heavy density medium – a slurry of sand and water. The raw coal is fed into a conical separating chamber which contains the mixture of sand and water, the sand being kept in suspension in the water by movement of a revolving agitator. The coal (specific gravity of anthracite = 1.70 or higher, bituminous coal = 1.50) floats near the surface of this fluid mixture and circulates around the cone until it reaches the discharge point. The heavier impurities, meanwhile, sink and fall through a classifying column into a refuse chamber.

Specifications for sand used in this process require a specific gravity of at least 2.64 which implies a clean quartz sand free of low density rock fragments. The grains must be subangular to round and free of sharp edges and corners. Iron oxide coatings are not objectionable if they adhere firmly enough so that they do not wear off in the washing process. The sand should be free from clay and organic matter.

Ideal particle-size distribution for coalwashing sand ranges between -30 mesh to +140 mesh with at least 90 per cent between -30 to +100 mesh.

The Conklin process, employed commonly in Alberta, is based on the same principle as the Chance process but uses magnetite rather than sand. Magnetite has the advantage over sand in that its specific gravity is higher (5.0 against 2.6) and for this reason the mixture contains a lower proportion of solid material (Chapman and Mott, 1928, p. 390). However, because of its higher specific gravity, the solid particles have a greater tendency to separate out from suspension, and must, therefore, be used in a finer state of division (200-mesh).

Engine (Locomotive or traction) Sand

Railroads use large quantities of engine sand to provide greater traction for locomotives on wet or slippery rails. The requirements are a clean, hard sand, uniform in grain size, and free of clay so as to allow rapid and steady flowage. Either rounded or angular grains are suitable, but extremely spherical grains tend to roll off the rails before being caught under the driving wheels. The desirable size distribution ranges between 20 and 80 mesh.

The Canadian National and Canadian Pacific Railroads are guided by the specifications of the Association of American Railroads (Specifications M916-51, Car and Locomotive Sand, adopted 1950). The sand should be a clean silica sand free from clay, loam, mica, and other foreign material. It should have a minimum silica content of 90 per cent and have satisfactory noncaking properties. The sand should run freely through a 1/2 inch opening at the bottom of a container without shaking or tapping. Grain size requirements are:

U.S. Standard Sieve No.	Opening (mm)	Per Cent Passing
10	2.00	100
30	0.60	40
50	0.30	10-30 (max)
80	0.18	5 (max)

The Canadian National Railway uses a carload of sand a week out of Edmonton. The sand presently is supplied from a local source and has the following size distribution:

U.S. Standard Sieve No.	Opening (mm)	Per Cent Passing
8	2.40	100
16	1.17	95-100
30	0.60	60-100
50	0.30	30-60
100	0.15	0-5

The Canadian Pacific Railway presently uses sand from a deposit in British Columbia.

Filter Sand

Silica sand is used as a filtering medium for the removal of undissolved solids and bacteria from municipal and industrial water supplies. The sands are placed in uniform layers over layers of properly sized crushed stone or coarse gravel. The upper layers of sand perform the filtering function with the lower, coarser layers acting as a support. A typical filter bed succession is given below (Water Conditioning Handbook, Permutit Co., 1943):

27" of fine sand 0.45 to 0.5 mm effective size (with well-formed floc[12] a coarser sand in the 0.66 to 0.75 mm effective size range may be employed)
3" of coarse sand 0.8 to 1.2 mm effective size
3" of 1/4" x 1/12" gravel
4" of 3/4" x 1/4" gravel
5" of 1 1/2" x 3/4" gravel
6" of 2 1/2" x 1 1/2" gravel
48" total depth

Uniformity of grain size and chemical inertness are prime considerations for a filter sand. The sand should be well sorted, hard, durable, high in quartz and free of grain coatings, clay, silt or organic matter. It must not contain constituents such as iron and manganese, which would react with chemicals used in treatment. Permissible solubility of the sand is dictated by the pH of the water to be filtered (commonly less than 5.0 per cent soluble). Grain shape requirements are not critical except that flat or elongated grains must be minimal (less than 1 per cent). The grain-size distribution of the sand is controlled primarily by a specified "effective size" and "uniformity coefficient" (Appendix B) as recommended by the American Water Works Association (AWWA). The particular grade of sand used in any filter depends upon local factors and engineering design.

The following are current specifications for some water filtration plants in Alberta:

City of Lethbridge (1969 specifications). The filter sand should be "hard silica sand

[12] Gelatinous precipitates formed by the reaction of coagulants with suspended particles. These particles gather together in clumps large enough to be held back by the filter medium.

free from dirt, vegetable or foreign matter, and be carefully washed, dried, cleaned, and graded so that it will have an effective size not less than 0.45 mm and not more than 0.55 mm, and uniformity coefficient less than 1.4 or more than 1.75. The filter sand and gravel furnished should be in full accord with the AWWA specifications regarding loss when immersed in warm hydrochloric acid for 24 hours" (maximum allowable loss 5 per cent).

City of Red Deer (1969 specifications). The effective size range should be 0.25 to 0.35 and the uniformity coefficient range 1.50 to 2.5. Local sand from Pine Lake currently is being used, the effective size of which is approximately 0.18 mm, and the uniformity coefficient approximately 2.89. The sand is "backwashed"[13] in the plant prior to its being put into use to wash out the fines and bring it within the required size range.

City of Medicine Hat (1969 specifications). Graded silica filter sand is specified with an effective size range of 0.40 mm to 0.60 mm and a uniformity coefficient of 1.4 to 1.8.

City of Calgary (1965 specifications). "All materials should be carefully selected, thoroughly washed and screened.

Samples of the sand shall be submitted to five cycles of immersion in concentrated sodium sulphate in accordance with the current method of test for soundness of aggregates (designation C-88 of the American Society of Testing Materials). Materials showing a loss of more than 5 per cent may be rejected by the engineers.

The sand is to be 95 per cent insoluble when crushed and digested for 24 hours in concentrated hydrochloric acid.

Sand No. 1 shall be limited to grains of such size that it will pass a No. 8 U.S. Standard sieve and will be retained on a No. 16 U.S. Standard sieve.

Sand No. 2 shall have an effective or 10 per cent size of not less than 0.48 mm and not more than 0.52 mm and shall have uniformity coefficient between 1.4 and 1.2. The 30 per cent size shall be between 0.52 and 0.62 mm. The 80 per cent size shall be between 0.62 and 0.84 mm."

The City of Calgary presently uses sand from DeWinton, Alberta.

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13 Jets of clean filtered water are passed through the filter sand in the opposite direction to flush out impurities.

City of Edmonton. Filter sand with the following size distribution presently is being used by the City of Edmonton:

U.S. Standard Sieve No.	Opening (mm)	Cumulative Per Cent Retained
16	1.17	<0.05
30	0.60	55-60
50	0.30	99.75
100	0.15	99.95

Most of the cities and larger towns in Alberta (currently about 40 in all) use sand filtration as a method of purifying their water supply. However, the market for filter sand is small, for the sand can be reused over periods of approximately five years, and each plant requires only a few hundred tons.

Ground Silica

(Silica flour, potter's flint, ground quartz, enamel frit)

Silica sand ground to a fine white powder is used as an extender in paint and varnish, as an abrasive ingredient in soaps and scouring powders (see Abrasives, p. 12), as a filler in insecticides and fertilizers, pastewood filler, oxychloride cement mixtures, refractory cement for oilwells, and various building products. Finely ground quartz is a major component (about 20 to 50 per cent) of normal ceramic bodies for making earthenware, porcelain, and sanitary ware. It is used to reduce the drying and firing shrinkage and give the body a certain rigidity to combat deformation. It also makes the body more porous, promotes quicker drying, and permits the escape of steam and other gases. Ground quartz also is used as a silica source for enamelling iron and steel in order to combine with or flux the basic oxides.

The general requirements for pulverized quartz are chemical purity, lack of color or tint (iron oxide must be kept to a minimum), sharpness (angularity), and fineness. The refractive index is important for ground quartz used in varnishes. The refractive index of quartz is very near that of most paint varnishes, but impurities will alter this index and may reduce transparency. For use in gypsum plaster preparations and especially in wallboard, the desirable properties are refractoriness, whiteness, and chemical inertness.

For ground quartz the silica sand should be glass grade with 0.05 per cent or less iron oxide (Fe_2O_3). Table 4 gives typical analyses of ground silicas.

Table 4. Representative physical and chemical analyses of ground silicas (Ottawa Silica Company, Ottawa, Illinois)

Representative Physical Analysis

Grade of Sand	U.S. Standard Sieve No. (per cent passing)			
	100	140	200	325
285	99.5	97	88	68
290		98.5	92.5	71
295			96	80
390			99.5	92.5
395				96
398				98

Representative Chemical Analysis

Constituent	Composition (%)
Silica (SiO_2)	99.80
Iron oxide (Fe_2O_3)	0.02
Aluminum oxide (Al_2O_3)	0.06
Titanium dioxide (TiO_2)	0.013
Calcium oxide (CaO)	0.01
Magnesium oxide (MgO)	0.01
Loss on ignition (L.O.I.)	0.09

Metallurgical Sand

Silica sand is used as a flux in smelting base metal ores in which iron and basic oxides react with the sand to form a silicate slag. Because free silica is the active slagging ingredient, the quartz content of the flux should be as high as possible. Iron, alumina, and basic oxide impurities are not objectionable except that they reduce the percentage of available silica. Therefore, if an inexpensive local source of lower grade quartz sand is available, it may be used in preference to more expensive, purer sand which must be hauled from some distance.

The largest users of metallurgical quartz sand in Canada are the copper-nickel smelters of the Sudbury area: the International Nickel Company uses more than 1 million tons annually. In the roasting plant of the nickel circuit at Copper Cliff, silica flux consisting of seven-eighths sand and one-eighth fine quartzite is mixed with nickel concentrates in the proportion of approximately 1 ton flux to 5 tons concentrates for feed to the roasters (Hewitt, 1963). At the present time there are no smelters in Alberta to provide a market for metallurgical sand.

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APPENDIX A.
SPECIFICATIONS AND PROPERTIES OF SILICA SANDS.

Table 5. Chemical compositions of commercial soda-lime-silica glasses (after Rawson, 1967)

Glass	Chemical Constituents (%)									
	SiO_2	Al_2O_3	MgO	CaO	BaO	Na_2O	K_2O	B_2O_3	SO_3	F_2
Containers	72.1	1.8	9.8		0.3	15.6		0.2	0.1	0.1
Rolled plate	70.5-73.0	0.5-1.5	0.1	13.0-14.0	-	12.0-14.0	-	-	-	-
Drawn sheet	71.0-73.0	0.5-1.5	1.5-3.5	8.0-10.0	-	14.0-16.0	-	-	-	-
Lamp bulbs	72.5	1.3	3.0	6.5	-	16.3		-	-	-
Fluorescent lamp tubing	71.5	2.2	3.0	5.7	1.7	14.0	1.5	-	-	-

Table 6. Chemical specifications for glass sand of some Canadian glass manufacturers

Company	Chemical Constituents (%)								Remarks
	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	TiO	ZnO_2	K_2O+Na_2O	
Consumers Glass Company Limited, Toronto, Ontario	99.70–99.99	<0.03	constant ±0.05	constant ± 0.03		<0.03	<0.0001	-	Flint glass For colored glass Fe_2O_3 can be as high as 0.06 per cent.
Corning Glass Works of Canada Ltd., Bracebridge, Ontario	99.50	0.027 (max.)	0.20 (max.)	0.02 (max.)	0.02 (max.)	0.025 (max.)	-	-	Total coloring oxides, except Fe_2O_3, <0.01 per cent.
Canadian Pittsburgh Industries Limited, Owen Sound, Ontario	99.60	0.015–0.03	0.03–0.05	0.05		0.02	-	-	Free of coloring oxides such as cobalt, copper, chromium, nickel, etc.
Pilkington Glass Manufacturing Limited, Scarborough, Ontario	99.50–100.00	0.027 (max.)	0.20 (max.)	0.05 (max.)		0.02 (max.)	-	0.10 (max.)	Float plate glass The content of heavy minerals of specific gravity >3.0 not to exceed 0.001 per cent. Total coloring oxides except Fe_2O_3 <0.0001 per cent.

Table 7. Grain size specifications for glass sand of some Canadian glass manufacturers (weight per cent passing)

U.S. Standard Sieve No.	Opening (mm)	Manufacturers			
		A	B	C	D
20	0.84	100	100	-	100
30	0.60	98	98 (min.)	100	96 (min.)
40	0.42	75	82 (min.)	-	-
60	0.25	-	-	-	30-45
80	0.18	-	-	10 (max.)	-
100	0.15	-	3 (max.)	-	10 (max.)
120	0.12	-	-	5 (max.)	4 (max.)
140	0.10	2 (max.)	-	-	-
200	0.07	-	-	-	-

A - Consumers Glass Company Limited, Toronto, Ontario

B - Corning Glass Works of Canada Ltd., Bracebridge, Ontario

C - Canadian Pittsburgh Industries Limited, Owen Sound, Ontario

D - Pilkington Glass Manufacturing Limited, Scarborough, Ontario

Table 8. Properties of some sandblasting sands used in Canada (after Cole *et al.*, 1932)

	U.S. Standard Sieve No.	Opening (mm)	Source of Sand: Imported Sand No. 1	Imported Sand No. 2	Three Rivers, Quebec	Two Mountains, Quebec	East Templeton, Quebec No. 3 (coarse)	East Templeton, Quebec No. 2 (fine)
Mechanical Analysis (per cent retained)	>20	>0.84	0.02	0.48	43.40	1.48	5.1	-
	20-30	0.84-0.60	3.17	37.37	12.69	1.67	22.7	0.5
	30-40	0.60-0.42	56.97	58.34	15.05	14.66	58.0	19.9
	40-50	0.42-0.30	26.89	3.55	13.20	40.63	13.2	41.7
	50-70	0.30-0.21	9.39	0.17	10.75	28.76	0.9	22.9
	70-100	0.21-0.15	2.90	0.06	3.99	9.09	0.1	11.0
	<100	<0.15	0.66	0.03	0.92	3.71	-	4.0
	TOTAL		100.00	100.00	100.00	100.00	100.00	100.00
Grain Shape (Roundness)			Rounded	Rounded	Angular with few subangular grains	Angular	Subangular to angular	Angular to subangular
Composition			98% quartz; few grains with hornblende inclusions.	99% quartz; few grains with hornblende inclusions.	78% quartz, 22% mica, feldspar, hornblende and scattered granitic fragments.	89% quartz, 11% mica, hornblende and feldspar.	99% quartz, 1% hornblende, magnetite and pyrite.	98% quartz, 2% hornblende, pyrite, mica and magnetite.

Table 9. Sources of some sandblasting sands used in Alberta

Use	U.S. Standard Sieve No.	Source of Sand
Cleaning tanks, pipes, etc.	20-40	Taber, Alberta (screenings from crushed gravel) Selkirk, Manitoba (Black Island silica sand deposit)
Pipeline cleaning (e.g. Alberta Gas Trunk Line).	30	Taber, Alberta (screenings from crushed gravel)
Cleaning metal surfaces prior to application of protective coating.	10-20	Eau Claire, Wisconsin Joplin, Mississippi
Engraving of monumental stone	30-40	Calgary, Alberta (screened glacial outwash sand)
General sandblasting.	20-40 unsized	Selkirk, Manitoba Edmonton, Alberta (local river sand, glacial outwash, dune sand)

Table 10. Properties of common "propping" (hydraulic fracturing) sand (after Hassebroek and Saunders, 1961)

	Grade	Opening (mm)	Permeability (darcys)	Packed State Porosity (%)
Angular	4-8[1]	4.76-2.38	-	-
Angular	8-12	2.38-1.68	1745	36
Angular	10-20	2.00-0.84	881	36
Rounded	10-20	2.00-0.84	325	32
Rounded	10-30	2.00-0.59	191	33
Rounded	20-40	0.84-0.42	121	35
Rounded	40-60	0.42-0.25	45	32

[1] U.S. Standard Sieve No.

Table 11. Characteristics of hydraulic fracturing sand used in Alberta (courtesy Cardium Supply Ltd., Edmonton, Alberta)

Representative Physical Analysis

	U.S. Standard Sieve No.	Opening (mm)	Grades Commonly Specified			
			10-20	12-30	20-40	30-60
Mechanical Analysis (per cent retained)	>16	>1.17	10.5	3.7	-	-
	16-20	1.17-0.84	79.5	46.1	4.0	-
	20-30	0.84-0.60	9.8	46.2	44.7	1.4
	30-40	0.60-0.42	0.2	4.0	47.3	38.6
	40-50	0.42-0.30	-	-	4.0	48.8
	50-70	0.30-0.21	-	-	tr	10.2
	70-100	0.21-0.15	-	-	-	0.9
	100-140	0.15-0.10	-	-	-	0.1

Average porosity:	34% compacted 40% uncompacted
Specific gravity:	2.63
Bulk weight:	105.91 lbs/ft^3 14.14 lbs/gal
Absolute volume:	4.57 gal (0.611 ft^3)/100 lbs 4.83 gal (0.646 ft^3)/ft^3
Bulk volume:	0.945 ft^3(7.07 gal)/100 lbs

Representative Chemical Analysis

Constituent	Per Cent
Silica (SiO_2)	99.770
Iron oxide (Fe_2O_3)	0.026
Aluminum oxide (Al_2O_3)	0.045
Calcium oxide (CaO)	tr
Magnesium oxide (MgO_2)	0.014
Titanium dioxide (TiO_2)	0.006
Loss on ignition	0.120

Table 12. Properties of molding sand for use with various casting alloys (after Wolf, 1951)

Casting Alloy	Minimum Sintering Temperature [1] (°F)	Green Compression Strength (lbs/in^2)	Permeability [2]	AFS Clay (%)	AFS Grain Fineness Number	Moisture (%)
Aluminum castings	2350	6.5-7.5	7-13	12-18	225-160	6.5-8.5
Brass and bronze castings	2350	7.0-8.0	13-20	12-14	150-140	6.0-8.0
Light gray iron, stove-plate castings	2350	6.0-7.5	10-15	10-12	200-180	6.5-8.5
Light gray iron, squeeze molds	2400	6.2-7.5	18-25	12-14	120-87	6.0-7.5
Medium gray iron (floor molding)	2400	7.5-8.0	40-60	11-14	86-70	5.5-7.0
Medium gray iron, synthetic sand (for system conditioning)	2450	7.5-8.5	50-80	4-10	75-55	4.0-6.0
Heavy gray iron, green or dry sand	2500	5.0-7.5	80-120	8-13	61-50	4.0-6.5
Light steel castings, green sand	2600	4.5-7.5	60-200	2.5-10	80-45	2.0-4.0
Heavy steel castings, green sand	2700	4.5-7.5	100-300	3-10	68-45	2.0-4.0
Heavy steel castings, dry sand	2600	6.5-7.5	100-200	3-10	60-45	4.0-6.0

[1] Refractoriness
[2] Number of cm^3 of air at 1 g/cm^2 flowing through 1 cm^3

Table 13. Chemical compositions of some foundry sands

Source of Sand	Chemical Constituents (%)									Remarks
	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	FeO	
Key Sand, New Jersey	91.11	1.040	4.77	0.25	0.18	0.12	0.09	0.14	0.15	Core sand (Weigel, 1927)
Ottawa, Illinois	99.48	0.020	0.16	n.d.	0.11	0.05	-	-	-	Silica sand (Weigel, 1927)
Richland, New Jersey	86.46	1.040	6.95	0.41	0.16	0.41	0.21	0.58	0.31	Iron and nonferrous molding sand (Weigel, 1927)
Albany, New York	75.91	3.260	9.44	0.64	1.12	0.64	1.42	2.96	1.86	Naturally bonded molding sand (Weigel, 1927)
Wedron, Illinois	99.59	0.019	0.17	0.02	0.01	tr.	-	-	-	Silica sand (pers. comm.)
Leighton Buzzard, United Kingdom	99.26	0.150	0.24	0.06	0.18	0.04	-	-	-	Silica sand (Parkes, 1950)
King's Lynn, United Kingdom	99.24	0.060	0.48	-	0.12	-	-	-	-	Silica sand (Parkes, 1950)

Table 14. Grain size data and other properties of a naturally bonded molding sand (after Ries, 1949)

Grade of Sand	U.S. Standard Sieve No. (per cent retained)													AFS Gr. Fi. No.[1]	AFS Perm.[2]	Green Sh. Str.[3] (psi)	Green Comp.[4] (psi)
	6	12	20	30	40	50	70	100	140	200	270	Pan	Clay				
Albany																	
00	-	0.02	0.02	0.04	0.04	0.06	0.16	0.74	2.36	12.12	16.30	54.44	13.68	250	7.2	2.0	7.4
1	-	0.02	0.04	0.10	0.24	0.94	3.14	9.50	14.92	23.60	13.28	23.24	10.98	172	14.0	1.6	5.6
2	-	-	0.06	0.20	1.54	11.04	20.64	20.76	9.54	7.70	3.72	9.34	15.46	101	31.0	1.8	6.1
3	-	0.18	0.44	2.14	9.46	19.92	24.60	16.40	4.80	3.94	1.96	5.10	11.06	73	96.0	1.0	4.4
4	0.18	1.06	3.22	3.24	15.20	29.84	20.52	5.62	1.42	1.50	0.90	4.40	10.90	57	178.0	1.0	4.2

[1] AFS Grain Fineness Number
[2] AFS Permeability
[3] Green Sheer Strength
[4] Green Compression

Table 15. Grain size data and AFS grain fineness numbers for various molding sands (after Rose, 1950)

Source of Sand	U.S. Standard Sieve No. (per cent retained)										AFS Grain Fineness Number
	20	30	40	50	70	100	140	200	270	Pan	
Ottawa, Illinois	1.2	30.2	55.8	5.7	1.6	1.4	1.6	0.8	0.6	1.1	34
Ottawa, Illinois	-	0.6	29.2	33.6	15.8	9.8	6.8	2.6	1.2	0.4	51
Crystal City, Missouri	0.1	0.2	3.4	23.0	37.7	19.9	10.8	3.4	0.8	0.6	62
Roff, Oklahoma	-	-	0.6	3.4	9.4	38.4	38.0	9.6	1.0	0.4	84
	0.1	0.1	0.4	2.3	7.4	21.8	45.6	18.5	3.2	0.7	100
Sulphur, Oklahoma	0.2	0.4	0.6	0.8	1.5	23.3	48.2	16.8	3.4	4.8	111

Table 16. Types and sources of sands used by Alberta foundries

Foundry	Metals Cast	Sand	Grain Size	Source
Albronze Foundry Ltd., Calgary	Copper and alloys Aluminum and alloys	Olivine	120 mesh	Seattle, Washington
Anthes Western Limited, Calgary	Grey iron, ductile iron	Silica	AFS GFN 65 20 - 100 mesh	Selkirk, Manitoba Taber, Alberta
Dominion Bridge Co. Ltd., Edmonton	Grey iron, alloy iron, Ni hard and Ni resist ductile iron, aluminum	Silica	AFS GFN 20 - 40 AFS GFN 65	Selkirk, Manitoba
Irving Industries Limited, (Foothills Steel Foundry Division), Calgary	Grey iron, steel Manganese steel	Silica	AFS GFN 68 (approx.) (see table 17)	Wedron, Illinois
Lethbridge Iron Works Company Limited, Lethbridge	Grey iron, ductile iron	Silica	AFS GFN 40 - 60 AFS GFN 70	Selkirk, Manitoba
Crane Canada Limited, McAvity Division, Medicine Hat	Grey iron Copper and alloys	Silica (dune sand)	40 - 140 mesh	Saskatchewan
Norwood Foundry Limited, Edmonton	Grey iron, ductile iron Copper and alloys Aluminum and alloys	Silica	AFS GFN 61 (approx.) (see table 17)	Selkirk, Manitoba
Quality Steel Foundries Ltd., Edmonton	Steel Copper and alloys	Silica Zircon Olivine	30 - 65 mesh	Selkirk, Manitoba Australia Seattle, Washington

Table 17. Properties of molding sands used by two Alberta foundries

	U.S. Standard Sieve No.	Opening (mm)	Source of Sand	
			Wedron, Illinois[1]	Selkirk, Manitoba[2]
Mechanical Analysis (per cent retained)	20-30	0.84-0.59	-	-
	30-40	0.59-0.42	2.7	2.8
	40-50	0.42-0.30	14.8	16.4
	50-70	0.30-0.21	30.0	31.8
	70-100	0.21-0.15	32.0	35.7
	100-140	0.15-0.10	15.8	12.0
	140-200	0.10-0.07	3.7	0.9
	200-270	0.07-0.05	-	0.1
	<270	<0.05	1.0	-
AFS Grain Fineness Number			68.11	61.9
AFS clay (per cent)			-	0.48
Base permeability (dry)			80	-
Chemical Analysis (per cent)	Silica (SiO_2)		99.59	99.70
	Iron oxide (Fe_2O_3)		0.019	<0.06
	Aluminum oxide (Al_2O_3)		0.17	0.10
	Titanium dioxide (TiO_2)		0.017	
	Calcium oxide (CaO)		0.010	
	Magnesium oxide (MgO)		tr	
	Loss on ignition		0.19	

[1] Irving Industries Foothills Steel Foundry Division Ltd.
[2] Norwood Foundry Limited

Table 18. Grain size data and AFS grain fineness numbers for various core sands (after Rose, 1950)

Sand [1]	U.S. Standard Sieve No. (per cent retained)										AFS Grain Fineness Number
	20	30	40	50	70	100	140	200	270	Pan	
E.S. Glynn core sand	1.1	3.0	14.0	41.0	31.3	6.2	1.1	0.2	0.4	1.2	45
Canfield No. 2 core sand	1.1	4.3	17.2	40.0	23.8	6.8	4.6	1.3	0.5	0.4	47
Rees core sand		0.1	0.8	13.0	48.4	27.4	7.0	1.2	0.2	0.9	61
Cochran core sand	0.1	0.5	2.9	10.4	25.4	28.1	20.2	6.6	1.8	1.8	78
Canfield No. 1 core sand		0.1	0.3	2.9	28.9	34.0	24.7	6.6	0.9	1.1	79

[1] The core sands listed here are all produced in Kansas

Table 19. Grain size data for typical furnace sands (after Weigel, 1927)

	U.S. Standard Sieve No.	Opening (mm)	Source of Sand		
			New Jersey	Ohio	Pennsylvania
Mechanical Analysis (cumulative per cent retained)	12	1.68	-	0.70	1.10
	20	0.84	-	2.90	2.20
	40	0.42	0.80	28.70	7.90
	70	0.21	19.30	82.40	65.50
	100	0.15	78.40	94.32	82.40
	200	0.07	95.80	98.80	89.40
	<200	<0.07	100.00	100 00	100.00

APPENDIX B

PARTICLE-SIZE DISTRIBUTION IN SANDS

Descriptive terms applied to sand are based on particle-size distribution parameters according to one or other of the schemes shown in figure 1. Commonly specified size ranges of silica sand for some of its many industrial uses are given in figure 2.

The particle-size distribution of a sand sample is determined conventionally by removing the clay-size material then passing the sand fraction through a series of sieves of predetermined mesh sizes. The amount of material retained on each sieve and on the bottom pan is then weighed and the results converted to percentages of the total sample weight. This procedure is called mechanical analysis and is done according to the procedure set out by the American Society for Testing Materials (ASTM Designation C429-65). The sieve numbers and sizes of openings of standard sieves are given in table 20.

The results of mechanical analysis can be presented in a number of ways (Krumbein and Pettijohn, 1938, p. 182-211), some of the most common graphic procedures are shown schematically in figure 3. All these procedures use grain size (mm) as the horizontal scale (abscissa) and frequency, expressed usually as weight per cent, as the vertical scale (ordinate). The results can be plotted on either an arithmetic or a logarithmic base.

Histogram (Fig. 3A). A histogram is a bar graph in which the weight-percentages of material in each size class are plotted in columnar form. Conventionally, the columns (i.e., size-class intervals) are of equal widths on a logarithmic scale based on multiples of 10 (MIT grade scale) or 2 (Wentworth grade scale). Although some general idea of the size-sorting characteristics of a sand can be visualized from a histogram, this graphic technique has little value in quantitative analysis.

Frequency curve (Fig. 3B). A frequency curve is a modification of the discontinuous bar graph presentation in a histogram and can be obtained by superimposing a smooth curve over the histogram bars. The frequency curve is a more preferable device for depicting grain size characteristics than a histogram, for the median, sorting coefficient, and other pertinent statistics can be estimated from it. This procedure, however, is not entirely satisfactory, the unique size-frequency distribution of a mechanically analyzed material can be obtained more precisely from the cumulative frequency distribution described below.

Cumulative frequency curve (Fig. 3C) A cumulative curve is a continuous frequency curve which portrays the amount of material larger (or smaller) than a given grain-size diameter. It is constructed from the grain-size data by adding in a cumulative manner the percentages of material in successive size-class intervals.

Thus, the frequency (ordinate) extends from a value of zero for the largest (or smallest, depending on the "direction" of the curve) class interval to 100 per cent at the other end of the scale. The shape of the curve is theoretically independent of the number and mesh openings of sieves used.

Figure 4 illustrates the results of an actual mechanical analysis of a sand, summarized in the form of a cumulative frequency distribution curve. The sieve numbers and openings are given at the top of the diagram, together with the percentages of material retained on each sieve and the percentages of the total sample finer than the associated sieve (mesh) size. The last-named percentages are plotted below on the corresponding grain-size intercepts of the cumulative frequency diagram, which are on a logarithmic scale, and the "best fit" curve has been drawn through the points.

A number of features associated with the mechanically analyzed material can be obtained from the cumulative curve. The median (or average) grain size of the material is read directly from the 50 per cent intercept on the cumulative curve; in figure 4 it is 0.43 mm, described as "medium sand" by the MIT classification used by engineers. The degree of sorting or uniformity of the sand is described by the coefficient of uniformity, which is calculated from the formula:

$$C_u = D_{60}/D_{10}$$

where D_{60} = grain size corresponding to the 60 per cent intercept on the cumulative curve,

D_{10} = grain size corresponding to the 10 per cent intercept on the cumulative curve (effective grain size).

Thus, as the material becomes less uniform (or more poorly sorted) the value of C_u increases proportionately. Needless to say, the classification of a material as "well sorted," "poorly sorted," etc. is a relative concept and depends upon the use to which the data is to be put. A wide variety of other grain-size statistics can be calculated from cumulative frequency distributions; these are described in a number of standard reference works on sedimentology and soil mechanics.

Authority	Designation
Trade Name	Minus 200 Mesh, Fines, Mineral Filler; Fine Aggregate; Coarse Aggregate
Wentworth	Clay; Silt; Very fine sand; Fine sand; Med. sand; Coarse sand; Very coarse sand; Granule; Cobble; Boulder
American Society for Testing Materials	Clay; Silt; Fine sand; Coarse sand; Gravel
United States Dept. of Agriculture	Clay; Silt; Very fine sand; Fine sand; Med. sand; Coarse sand; Very coarse sand; Fine gravel; Coarse gravel; Cobbles
Unified Soil Classification	Fines (silt and clay); Fine sand; Medium sand; Coarse sand; Fine gravel; Coarse gravel; Cobbles
Massachusetts Institute of Technology (M.I.T.)	Clay; Silt; Sand; Gravel
Tyler Mesh	200; 150; 100; 48; 35; 28; 14; 9; 8; 4
U.S. Standard Seive No.	200; 140; 100; 50; 40; 30; 16; 10; 8; 4
Inches	.0029; .0059; .0117; .0232; .0469; .0787; .157; .25; .5; .75; 1.0; 1.5; 2.0; 3.0; 6.0; 10.0
Millimeters	.002; .005; .01; .05; .1; .125; .25; .5; 1.0; 2.0; 10.0; 100; 1000

FIGURE 1. Classification of sediments

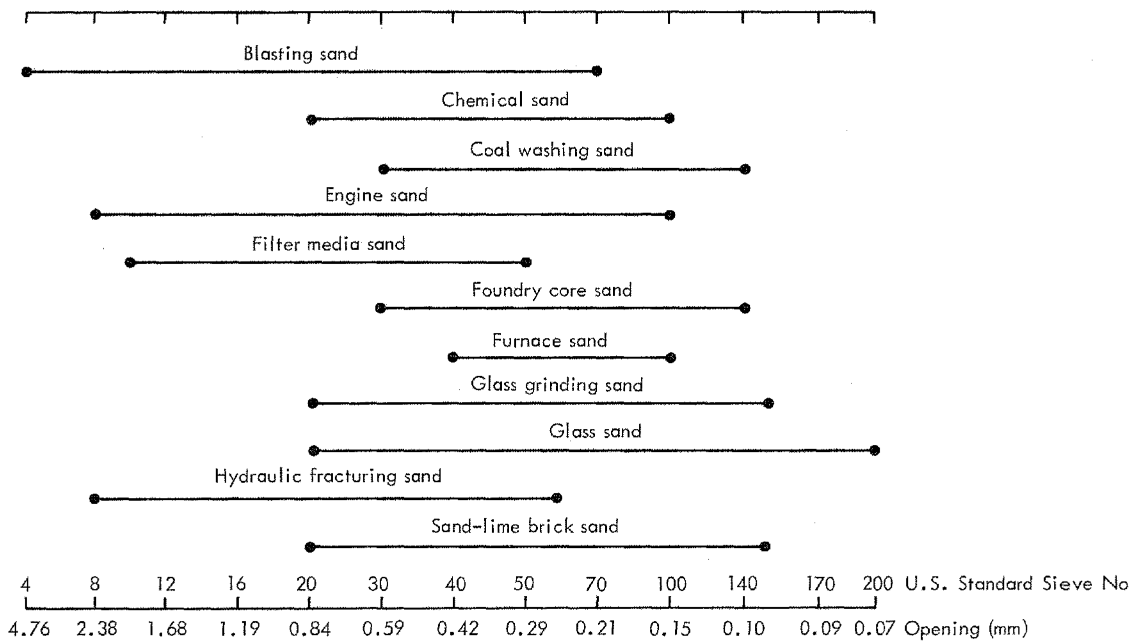

FIGURE 2. Commonly specified size ranges of silica sand

Table 20. U.S. Standard sieve series and Tyler equivalents

U.S. Standard Sieve No.	Tyler Screen Scale Sieves	Openings	
		millimeters	inches
4	4	4.760	0.1870
6	6	3.360	0.1320
8	8	2.380	0.0937
10	9	2.000	0.0787
12	10	1.681	0.0661
14	12	1.410	0.0555
16	14	1.190	0.0469
20	20	0.841	0.0331
30	28	0.595	0.0234
40	35	0.420	0.0165
50	48	0.297	0.0117
60	60	0.250	0.0098
70	65	0.210	0.0083
80	80	0.177	0.0070
100	100	0.149	0.0059
120	115	0.125	0.0049
140	150	0.105	0.0041
200	200	0.074	0.0029
270	270	0.053	0.0021
325	325	0.044	0.0017
400	400	0.037	0.0015

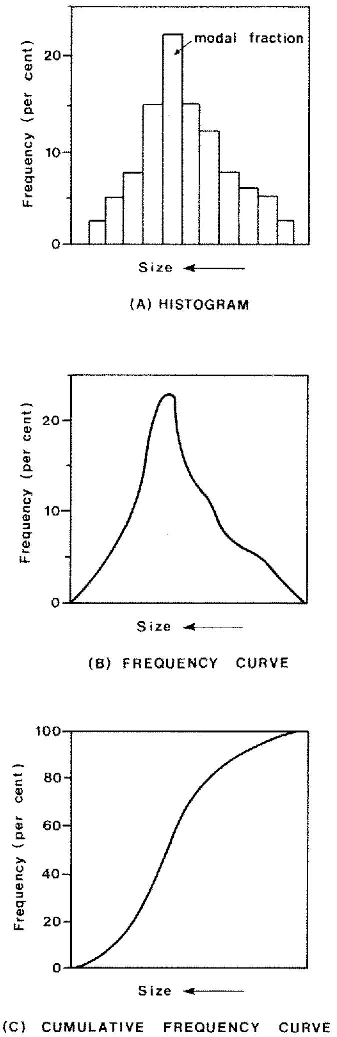

FIGURE 3. Graphic representation of mechanical analyses (after Leaming, 1968)

U.S. Standard Sieve No.	Opening (inches)	Opening (mm)	Per Cent Retained	Per Cent Finer[1]
-	0.3750	9.520	0.0	100.0
4	0.1850	4.760	1.2	98.8
10	0.0790	2.000	8.8	90.0
20	0.0331	0.840	15.1	74.9
40	0.0165	0.420	25.7	49.2
60	0.0097	0.250	25.6	23.6
100	0.0059	0.149	18.0	5.6
200	0.0029	0.074	3.8	1.8
>200	-	-	1.8	-

[1] Percentage of total sample finer than corresponding mesh size.

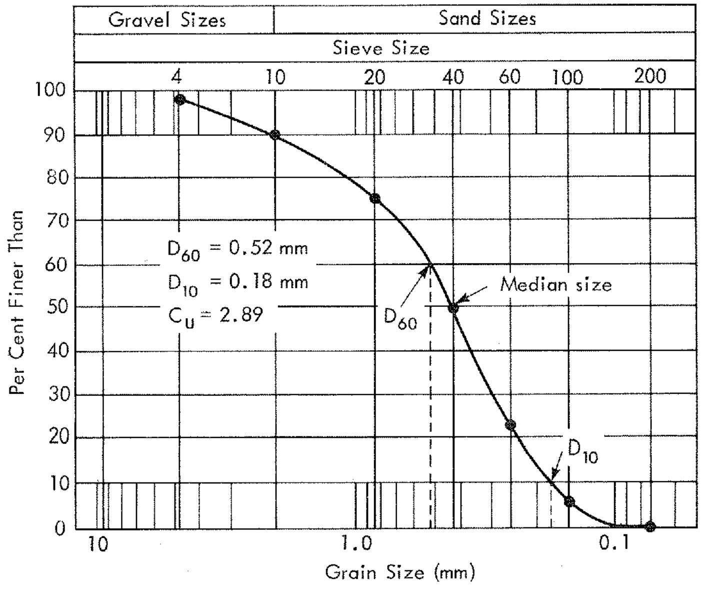

FIGURE 4. Cumulative frequency distribution of a sand

APPENDIX C

POTENTIAL SOURCES OF INDUSTRIAL SAND IN ALBERTA

Table 21 outlines the more common potential sources of industrial sand in Alberta. These are divided into two main groups – bedrock and surficial – and are cross-classified according to their origin or depositional environment.

Bedrock Sandstones and Conglomerates

Bedrock sandstones and conglomerates are the indurated or cemented equivalents of sand and gravel, respectively. Quartzose varieties range in age from Late Precambrian to Tertiary, forming a potential source of silica at several localities in Alberta.

Quartzites are hard indurated sandstones composed mainly of quartz grains completely cemented by silica with or without minor amounts of other minerals (iron oxides, carbonates). Examples are the Rocky Mountain Quartzite of Permo-Pennsylvanian age in the Rocky Mountains and the Athabasca Formation of Late Precambrian age in northeastern Alberta. Such materials would have to be quarried and crushed to specified grain sizes to provide a suitable source of silica sand.

Highly quartzose marine sandstones of Cretaceous age are exposed at several localities in northern Alberta. These are poorly cemented, friable rocks composed mainly of well-sorted, subrounded quartz grains that were deposited along the margins of ancient Cretaceous seas. The best known deposit, in the Peace River Formation exposed along the river of the same name in northwestern Alberta, is described in detail by Crockford (1949). Similar sandstones outcrop on the lower Athabasca River near Fort McMurray (Pelican Formation, Grand Rapids Formation) and in far northern Alberta along the flanks of the Birch Mountains.

The McMurray Formation of Lower Cretaceous age forms part of the Athabasca Oil Sands, exposed along the Athabasca River near Fort McMurray. The sands of this unit are composed mainly of fine-grained quartz, minor amounts of feldspar and muscovite (mica) "cemented" by heavy oil. They are presumed to be of fluvial origin, deposited in an ancient delta marginal to the early Cretaceous sea, and thus are interbedded with variable amounts of silt and clay. This deposit is described in detail by Carrigy (1966, 1971 in press)

Cypress Hills Conglomerate forms the hard bedrock cap on the upper slopes of the Cypress Hills in southeastern Alberta. It is composed mainly of hard quartzite pebbles and boulders cemented by a calcareous sandy matrix. It is the pebbles (derived from erosion and redeposition of older quartzite formations) which provide a potential source of silica, although they require crushing and screening to obtain suitable sand-size material. This deposit is described by Williams and Dyer

Table 21. Potential sources of industrial sands in Alberta

Type of Material	Stratigraphic Position		Origin: Fluvial	Origin: Shoreline	Origin: Aeolian
Surficial (sands and gravels)	Recent	Postglacial	alluvial	lacustine	dunes
	Pleistocene	Glacial	outwash eskers	lacustrine	
		Preglacial	Saskatchewan Sands and Gravels		
Bedrock (sandstone and conglomerate)	Tertiary		Cypress Hills conglomerate		
	Mesozoic		McMurray Formation	marine sandstones	
	Paleozoic and Late Precambrian			quartzites	

(1930) and, recently and in more detail, by Vonhof (1965). Similar sandy gravels cap the Hand Hills northeast of Drumheller.

Surficial Sands and Gravels

Surficial sands and gravels are found at numerous localities in most areas of Alberta, where they overlie bedrock or other unconsolidated deposits of Pleistocene and Recent ages. Most are of glacial origin, or are derived from glacial deposits, and tend to vary widely in composition and texture. Although many of these deposits have some value for construction purposes, few are sufficiently high in quartz to serve as a source of silica sand without some beneficiation to remove impurities. The more common types are:

"Saskatchewan" sands and gravels, a series of discontinuous, unconsolidated, feldspathic sands and gravels lying between bedrock and glacial deposits in various parts of central and southern Alberta. Of fluvial origin, the sands and gravels are heterogeneous in composition, consisting dominantly of quartzite particles with a high proportion of dark chert (microquartz) and feldspar particles. Coaly particles commonly are present. The deposits of central Alberta are described by Rutherford (1936, 1937), and of southern Alberta by Stalker (1963) and Westgate (1968).

Outwash sands and gravels are glaciofluvial sediments deposited marginal to a receding (melting) ice sheet. Such deposits are common in many areas of Alberta, varying greatly in thickness and extent. They generally are only moderately well sorted, with a high proportion of feldspars and dark mineral grains. Outwash sand has little potential as a source of silica but can be used as blasting sand and for a variety of construction purposes.

Esker deposits are texturally and compositionally similar to outwash sands and gravels. They are found as narrow sinuous ridges that may extend for several miles, having been deposited in meltwater channels within the ice sheet itself.

Lacustrine sands and silts deposited along the shorelines of ancient proglacial lakes are common in certain areas of Alberta. These sediments were derived by reworking other glacial deposits (outwash, till) in the same way that similar materials are being washed and sorted along the beaches of present-day lakes. Lacustrine sands are generally well sorted and cleaner than the parent materials from which they have been derived and, consequently, provide a potentially economic source of silica sand in areas where they are extensive.

Dune sands are common in many parts of the province, having been derived from adjacent sandy glacial deposits through prolonged wind action. Such sands are well sorted, generally fine- to medium-grained, and more siliceous than the parent material from which they have been derived. The accessibility, composition, and texture of these deposits make them a potentially economic source of industrial sand for a variety of purposes in central and southern Alberta (Carrigy, 1970).

Alluvial sands and gravels are found in variable amounts along most of Alberta's river valleys, either in the river bed itself, or as older terrace deposits above the present river levels. Investigations of the coarser-grained fractions of these deposits (Halferdahl, 1969) indicate that the more quartzose gravels may have some potential as a source of industrial silica.