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MINERAL WOOL FROM ASBESTOS TAILINGS

by

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MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

A mineral wool of good quality was prepared from a mixture of chrysotile asbestos tailings and sand from the Eastern Townships of Quebec. A nickeliferous by-product could be credited to process costs. Preliminary capital costing of the process indicates a viable operation returning over 20 per cent on investment before taxes.

Pilot plant studies are warranted to firm up the technical and economic considerations. Mor extensive market analysis is also desirable.

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Direction des mines
Rapport d'investigation IR 73-42

LAINE MINERALE A PARTIR DE RESIDUS D'AMIANTE

par

A. Winer* et H. S. Wilson*

RÉSUMÉ

Une laine minérale de bonne qualité a été préparée à partir d'un mélange de résidus d'amiante crysotile et de sable de la région des Cantons de l'Est au Québec. L'obtention d'un sous-produit de ferro-nickel pourrait permettre une diminution dans le coût des opérations. L'établissement préliminaire du coût du procédé permet d'entrevoir une opération rentable pouvant retourner plus de 20 pour cent sur investissement avant taxation.

Des études au niveau d'usine pilote sont ainsi justifiées, permettant d'établir et de confirmer certains faits d'ordre technique et économique. Une analyse plus approfondie du marché est aussi désirable.

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INTRODUCTION

The rapid expansion in the consumption of industrial minerals has caused an increase in the production of non-renewable resources. If this expansion continues at the present rate, these needs can only be met by new resource discoveries, by working lower grade ores, or by utilizing man-made resources such as the solid wastes from mineral processing plants.

There are many asbestos tailing piles in the Eastern Townships of Quebec. They represent an interesting and large resource. Because these tailings are in a "designated" area, this local resource is of interest for the manufacture of mineral wool.

ECONOMIC CONSIDERATIONS

Considerable quantities of materials such as impure limestone and slags are used in the manufacture of mineral wool. It is important that these be near large population centres (potential markets). Because mineral wool must be competitively sold, it is also essential that transportation costs be as low as possible. Only one wool insulation manufacturing plant exists in the Province of Quebec, so far as is known, in Montreal. A circle (125-mile radius), with Thetford Mines at the Centre, would include most of the large centres of population in Quebec and consequently the largest market for wool insulation products. Rail facilities are also excellent at Thetford Mines due to the provision for shipments of asbestos fibre which is mainly exported. Thus, some factors very necessary to choosing a plant location are already present.

From a breakdown of construction data for the Province of Quebec[1] and relating this to the percentage of construction (1970-72) for the area east of Manitoba, it was estimated that construction in Quebec was approximately 30 per cent of the total. Assuming that the proportion of mineral wool insulation would be equivalent to the proportion of construction, we have estimated that a total annual market for 46 million cu ft of insulation existed in Quebec in 1972.

A new plant could be expected to obtain 10 per cent of the market or 4.6 million cu ft having an estimated value of $1.04 million.

HISTORICAL

Manufacture and Uses of Mineral Wool

Mineral wool has been produced from many types of raw material. The first patent was issued in 1870, and the first recorded commercial manufacture was also in 1870, at Alexandria, Indiana. The rock was melted in a resistance arc furnace, the melt acting as one conductor. The temperature was maintained at 1538°C (2800°F). The melt was poured onto a high-speed revolving steel disc which spun the material into wool. A suction fan drew the wool into a collecting room. Shot was remelted and reblown.

A good grade of wool made in the Alexandria plant was analyzed as follows:

TABLE 1

Chemical Analysis of Alexandria Mineral Wool

	Per Cent
SiO_2	39.90
Fe_2O_3	1.34
Al_2O_3	14.86
CaO	31.46
MgO	11.69

Another method for producing mineral wool employs the cupola furnace which allows a stream of liquid drops to fall in front of a high-pressure jet of air.

A method different to those listed above is used in Britain[2]. The rock is melted and passed through holes in a platinum bushing. Steam at high speed fiberizes the melt. The fibres are collected on a moving belt. Typical properties of this wool are listed in the following table,

TABLE 2

Typical Properties of Rock Wool[2]

Specific gravity	2.87
Bulk density	20 to 192 kg/m^3
Mean fibre diameter	7 µm
Specific heat	7950 J/kg^oC
Fusion temperature	960^oC
Service temperature range (unbonded wool)	-230^oC to 900^oC
Sulphide content (S)	Less than 5 ppm
Boron content (B)	Less than 5 ppm
Chemical resistance (unbonded wool)	
Water	Excellent
Organic solvents	Excellent
Alkalis	Fair
Acids	Poor

Robertson[2] states that materials which form a melt with the system SiO_2 - Al_2O_3 - MgO - CaO, previously used in Britain, require constant attention due to viscosity changes. As little as one per cent change in silica would change the viscosity and cause problems. Currently, the system SiO_2 - Al_2O_3 - Fe_2O_3 - Feo - MgO is used. According to Robertson, this system is more consistent and imparts other properties required of insulation, e.g., infra-red radiation is said to be absorbed by the iron oxides.

Generally, the acid/base ratio is said to be between 0.8 to 1.2 for good mineral wool production[3]. Normally, SiO_2 and Al_2O_3 are considered to be acids, and CaO, MgO, Na_2O, K_2O, etc. to be bases. Alumina, however, plays an ambivalent role as an amphotheric substance but is generally considered to be acidic.

Goudge[4] stated that it was possible to make mineral wool from rock at temperatures above 1371°C (>2500°F), in which the acid/base ratio of the constituents was less than 0.8. This was true even where the magnesia was relatively high. At high temperatures, according to Goudge, MgO increased the viscosity ranges of the melts. However, the most economic operation is said to be where the acidic and basic constituents are about equal[5].

Thoenen[6] notes that the important variables in the manufacture of rock wool include: chemical composition which has an effect on the melting temperature of the mix; blowing temperature; length of drop of the melt stream to the blowing jet; and the viscosity of the slag. A theoretical treatment for the length of drop has been made by Saada and Mobarak[7]. A good discussion of these aspects of mineral wool production is given by Lathe[3].

The U. S. Bureau of Mines considers a satisfactory mineral wool to have the characteristics shown in Table 3.

TABLE 3

Characteristics of Satisfactory Mineral Wool

Average fibre diameter	-- 3 to 12 μm
Shot	-- less than 50% by weight
Sulphur	-- low
Melting temperature	-- approx 1538°C (2800°F)

SAMPLES

The asbestos tailings used in these experiments were obtained from three mines in the chrysotile asbestos producing area of the Eastern Townships of Quebec. These particular mines were chosen because they were representative of all the mines in the area. The results of the chemical analysis of these tailings are shown in Table 4.

TABLE 4

Chemical Analyses of Chrysotile Asbestos Tailings

Wt Per Cent

	H_2O	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	LOI
Mine #1	0.54	37.50	0.30	6.76	0.40	41.37	0.05	0.05	13.29
Mine #2	0.54	38.65	0.83	8.32	0.56	38.85	0.06	0.09	12.59
Mine #3	0.38	37.84	0.31	7.65	0.20	40.07	0.07	0.05	13.41

Chemical analyses of the materials added to the above tailings are shown in Table 5. These materials were added to the asbestos tailings in amounts estimated to give acid/base ratios of 0.8 to 1.2. However, in some instances the analysis of the samples were not available so estimates of the composition were made.

TABLE 5

Chemical Analyses of Materials Added to Tailings

Wt Per Cent

Material	H_2O	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	LOI
Phonolite (Varennes, Que.)	0.10	58.00	17.47	3.18	2.05	0.92	9.94	5.40	2.90
Sand (Sherbrooke, Que.)	–	75.60	8.93	3.82	2.54	1.93	1.84	1.75	3.24
Sand (Beauce Co., Que.)	–	75.24	10.46	4.13	2.21	1.34	1.82	2.06	2.69
Rock, (Road Cut near Marbleton, Que.)	–	19.74	2.10	0.82	41.78	0.85	–	–	33.05
Sand (Ottawa, Ill.)	–	99.8	0.05	0.02	0.03	0.01	–	–	0.07

The materials chosen for addition to the tailings, except for the Ottawa sand, were either waste products or economically available. The Ottawa sand was used to provide expertise in blowing wool.

PRELIMINARY EXPERIMENTS

Pyrometric cones, made from asbestos tailings (Mine #1) and mixed with various amounts of phonolite and of nepheline syenite, were heated in a gas-fired muffle kiln. The melting points are shown in Table 6.

TABLE 6

Melting Temperature of Cones

A. Per Cent Phonolite in Mixture	Melting Temperature °C	°F
30	1380	(2516)
40	1315	(2399)
50	1250	(2282)

B. Per Cent Nephylene Syenite in Mixture	Melting Temperature °C	°F
25	1430	(2606)
30	1370	(2498)
40	1245	(2273)
50	1205	(2201)

EQUIPMENT AND PROCEDURE FOR PRODUCING MINERAL WOOL

The furnace was a single-phase, two electrode 60 kVA arc unit. The electrodes were 1.5-inch rods and the furnace shell was 18 inches in diameter, 13 inches deep, and lined with about 3 inches of refractory material. The lid containing the electrodes can be pivotted away from the pot, and the pot can be tipped to pour the melt, as shown in Figure 2.

The weight of the charges were standardized at about 15 pounds, which was the optimum for the pot. In some tests, the pot was preheated before receiving the charge. Air hose (90 psi) was placed under the lip of the furnace. A collection bin, with a fan at the end to exhaust the loose siliceous dust from the atmosphere, was placed 15 ft from the furnace. This equipment is shown in Figures 1 to 5.

Melting of Mixture in Arc Furnace

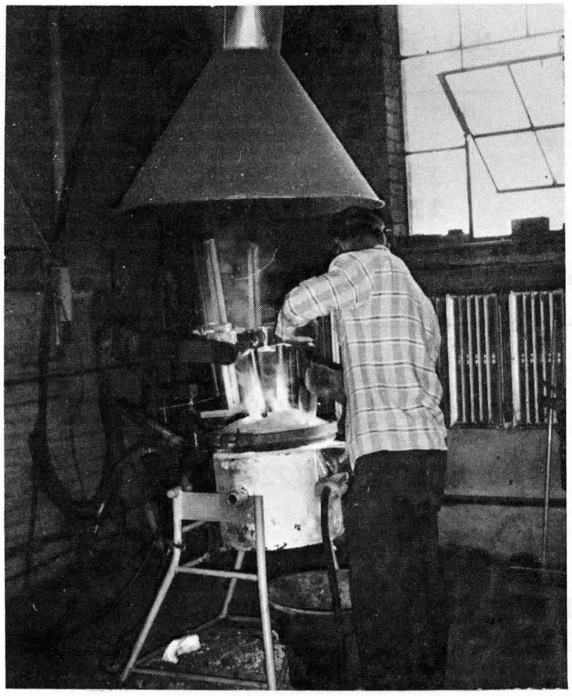

Figure 1 - Arc furnace; melting of mixture

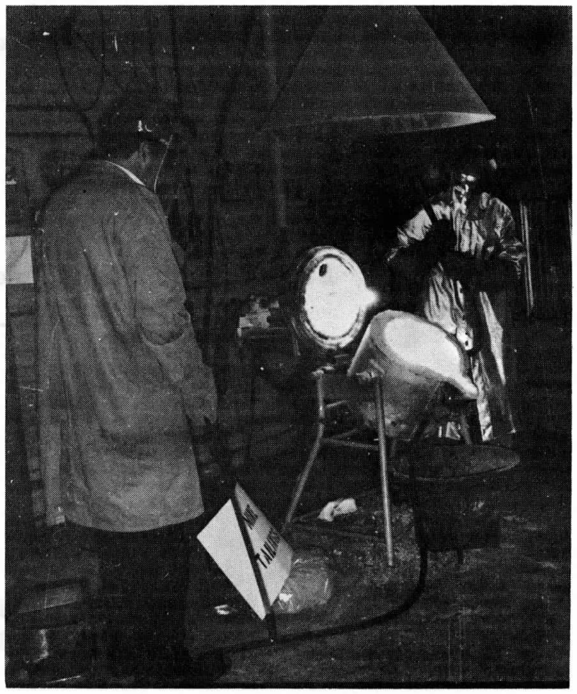

Figure 2 - Arc furnace; mixture melted and at flow temperture. Note air hose under lip of furnace

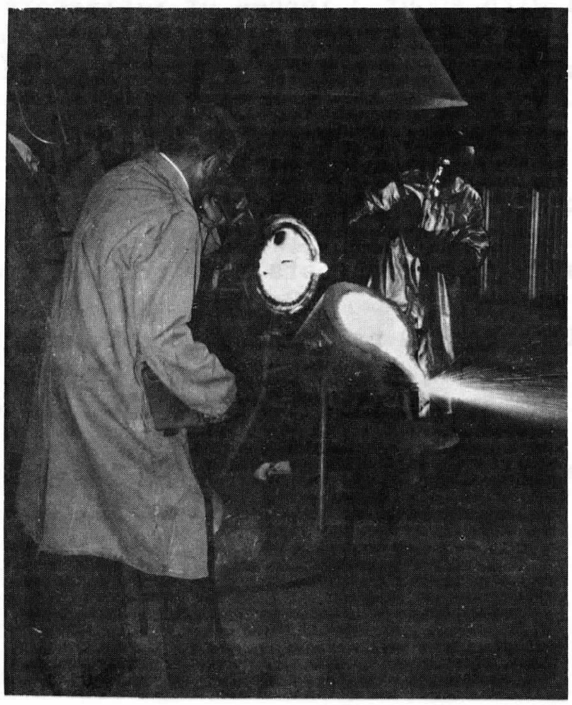

Figure 3 - Blowing mineral wool

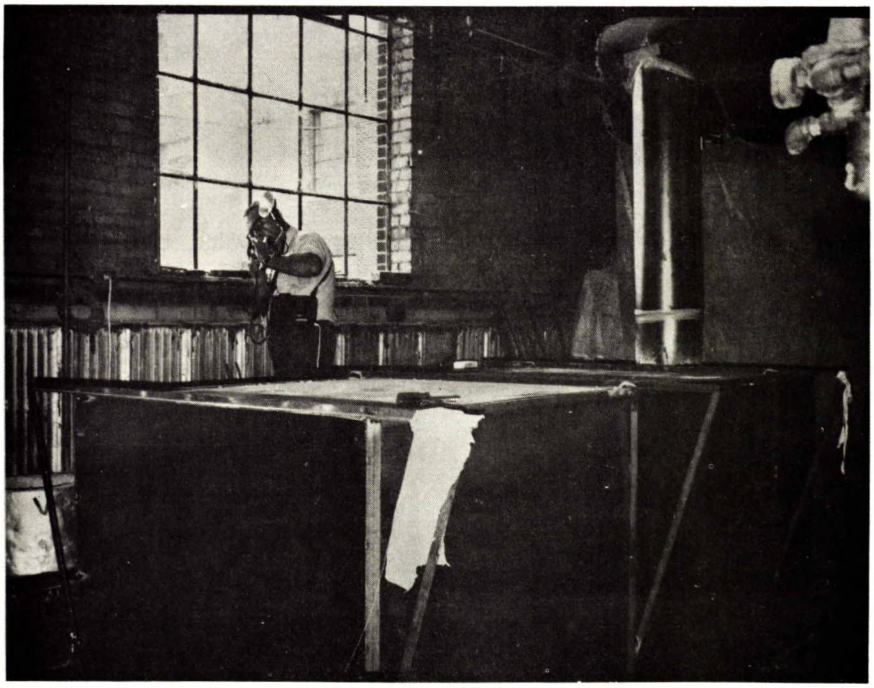

Figure 4 - Collection bin with suction fan at end.

Figure 5 - Removing solidified material from arc furnace.

The charge, previously mixed, was placed in the pot and brought up to about 1538°C (2800°F). After the charge was completely melted, the air valve was opened and the melt was poured into the air stream. The air broke the melt into droplets which fiberized to form mineral wool. Charge No. 1 and the melts from Charges No. 1 to 7 were chemically analyzed (Tables 7 and 8). The analysis of Charge No. 1 was included to compare it with the melt. It was assumed the fibre was similar in composition to its melt.

Observations and results from the various tests are shown in Tables 7 to 9.

TABLE 7

Chemical Analysis of Charge No. 1*
(Wt Per Cent)

SiO_2	52.57
Tot Fe as Fe_2O_3	6.33
Ni	0.08
CaO	4.04
MgO	34.96
Al_2O_3	3.50

* Chemical Analysis by Mineral Sciences Division

TABLE 8

Chemical Analysis of Melts
(Wt Per Cent)

Sample	SiO_2	Al_2O_3	Tot Fe as Fe_2O_3	Ni	CaO	MgO	Na_2O
Melt No. 1	52.67	3.25	6.83	0.10	4.04	35.03	-
" " 2	54.01	2.34	6.84	0.06	2.09	36.03	-
" " 3	54.56	0.85	5.74	0.08	0.84	39.44	-
" " 4	40.40	6.45	5.77	0.12	11.38	33.32	2.16
" " 5	43.36	8.00	5.70	0.10	4.20	39.84	0.97
" " 6	41.96	4.66	6.74	0.09	0.85	42.86	1.27
" " 7	37.24	0.80	7.70	0.19	11.80	42.58	0.34

TABLE 9

Summary of Observations - First Series, Carbon Arc Furnace

Sample Charge No.	Material Added to Tailings - Per Cent		Melt or Pour Temp °C	°F	Remarks
1	Ottawa Sand	20.5	1538	(2800)	Mineral wool blown, metallic button at bottom of melt.
2	" "	17.8	1538	(2800)	Mineral wool blown, more shot than in No. 1, metallic button at bottom of melt.
3	" "	19.3	1565	(2850)	Mineral wool, less shot and better wool due to air being blown horizontally.
4	Phonolite CaO	50.0 24.2	1554	(2830)	Practically no wool.
5	Phonolite	26.6	1620	(2950)	Practically no wool.
6	Nepheline Syenite	18.0	1538	(2800)	No wool.
7	Roadcut, dolomitic material	24.2	1538	(2800)	No wool.

Metallic buttons were present at the bottom of the melts and one of these from Charge No. 1 was analyzed mineralogically.

A petrographic study suggested that the button contained pyroxene, glass, and an unknown crystalline phase, but X-ray diffraction showed that only olivine had crystallized.

CALCULATIONS

Acid/base ratios were calculated on a weight per cent basis. This was the simplest method of calculation and is used in many U.S. Bureau of Mines experiments and by Logan[8]. At times, because the analysis was not yet available, assumptions as to quantities were made and recalculated later.

Table No. 10 shows the charges or melts and the corresponding acid/base ratios, Al_2O_3 being considered acidic in all cases and FeO or Fe_2O_3 basic.

TABLE 10

Acid/Base Ratios

Sample	Acid/Base Ratio by wt.	Remarks
Charge No. 1	1.2	Good wool
Melt No. 1	1.2	
Melt No. 2	--	--
Melt No. 3	1.2	Good wool
Melt No. 4	0.89	Small amount of wool
Melt No. 5	1.01	Small amount of wool
Melt No. 6	0.90	No wool
Melt No. 7	0.61	No wool

TRIALS IN REMMEY FURNACE

While the arc furnace was unavailable, A Remmey gas-fired furnace was used for further testing. These tests served to give guidance on the behaviour of the local Quebec sands when added to the asbestos tailings of Mine No. 1.

A crucible charge of 100 grams was melted and poured slowly into a horizontal jet of air. In one case, Na_2O was added to the charge to lower its melting temperature.

In these trials, the acid/base ratios of the charges containing the Sherbrooke sand were calculated to be slightly more than 1.1. Because the analysis for the Beauce Co. sand was not avilable, analysis of the constituents were assumed so that acid/base ratios could be calculated in making up different charges.

The observations are summarized in Table 11.

TABLE 11

Summary of Observations - Remmey Furnace Tests

Material Added to Tailings Per Cent	Pour Temp °C	Pour Temp °F	Remarks
Sand (Sherbrooke, Que) - 20%	1499	(2730)	Liquid too viscous; fibre wool too coarse.
Sand " " - 20%	1538	(2800)	Fibre too coarse.
Sand (Beauce Co., Que) - 20%	1538	(2800)	Fibre too coarse.
Sand (Sherbrooke, Que) - 15% plus Na_2O - 10%	1538	(2800)	Fair wool formed with some shot.
Sand (Beauce Co., Que) - 10%			Crucible melted and reacted with hearth.
Sand (Beauce Co., Que) - 15%	1555	(2832)	An MgO crucible was used to avoid a reaction; fine wool formed.

Discussion of Remmey Furnace Trials

Under the conditions of these tests, it was apparent that the pour temperature of the tests should be about 1554°C (2830°F), which coincides with the phase diagram information[9, 10]. The Na_2O added in one case did lower the melting temperature but this also probably rendered the acid/base ratio too low for good mineral wool production. In all cases, where wool was formed, the shot content was relatively high but this may have been due to the conditions of the test as much as to the viscosity of the melt.

CARBON ARC FURNACE TRIALS - SECOND SERIES

Because the Beauce Co. sand additions produced mineral wool of fair quality and because the sand appeared to be more uniform, it was used for these trials in the arc furnace. The cost of Beauce Co. sand, including transportation, was also less than that from Sherbrooke, Que.[11].

After this furnace was again available, charges were made up from Beauce Co. sand and asbestos tailings from mine No. 2. The charges all weighed about 15 pounds, as in the previous carbon-arc furnace runs. The acid/base ratios had to be estimated because no analysis of the sand was at hand, and additions of sand were made to obtain estimated acid/base ratios between 0.8 and 1.2

Observations on these runs are shown in Table 12.

TABLE 12

Summary of Observations for Second Series - Carbon Arc Furnace

Sample	Amount of Beauce Co. Sand Added - Per Cent	Pour Temp °C	Pour Temp (°F)	Remarks
Mine No. 2	5	1538	2800	No wool; all black shot.
Asbestos tailings	20	1538	2800	Very fine short fibre (green-grey); mostly shot by weight.
	25	1538	2800	Grey fibre; still large amount of shot.
	30	1538	2800	Lighter-grey fibre; much smaller amount of shot.
	35	1538	2800	Light grey-blue fibre; even smaller amount of shot.
	40	1538	2800	Light-grey fibre; low shot content.
	45	1538	2800	Off-white fibre; very low shot content.
	50	1538	2800	Off-white to blue-white fibre; low shot content

When the chemical analysis of the Beauce Co. sand was received, the acid/base ratios were recalculated. The results are shown in Table 13.

TABLE 13

Acid/Base Ratios by Weight for A Mixture of
Asbestos Tailings (Mine No. 2) and Beauce Co. Sand

Sand Addition Per Cent	Acid/Base Ratio (Al_2O_3 taken as basic)	Acid/Base Ratio (Al_2O_3 taken as acidic)
10	0.92	1.00
20	1.08	1.23
30	1.22	1.44
35	1.31	1.58
40	1.40	1.74
45	1.51	1.92
50	1.62	2.10

It is interesting to note that Thoenen(6) and others have stated that an acid/base ratio of between 0.8 and 1.2 produces good wool. However, if one considers alumina (Al_2O_3), there is much controversey as to whether this is to be considered acidic or basic. Lathe(3) has stated that alumina is generally considered acidic and the calculations in this report have been based on that premise. However, on a weight basis, the acid/base ratio is generally higher, so allowances should be made for this. Thoenen(6) has mentioned good wools in which the acid/base ratios were much higher than 1. The U.S. Bureau of Mines(12), in producing a glass wool experimentally, showed acid/base ratios between 0.9 and 2.07, assuming alumina (Al_2O_3) as acidic.

Measurements were made of the wool-fibre diameter by mounting the fibres between glass slides and obtaining microphotographs with Polaroid film and at 125X magnification. Microphotographs of the wool fibre produced from the charge containing 45 per cent sand from Beauce Co. are shown in Figures 6A and 6B.

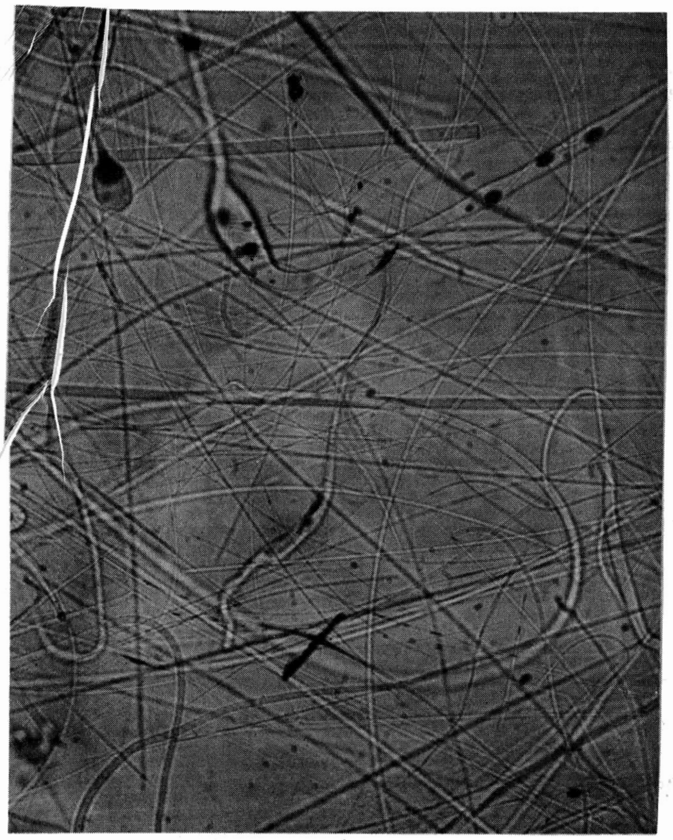

Figure 6A

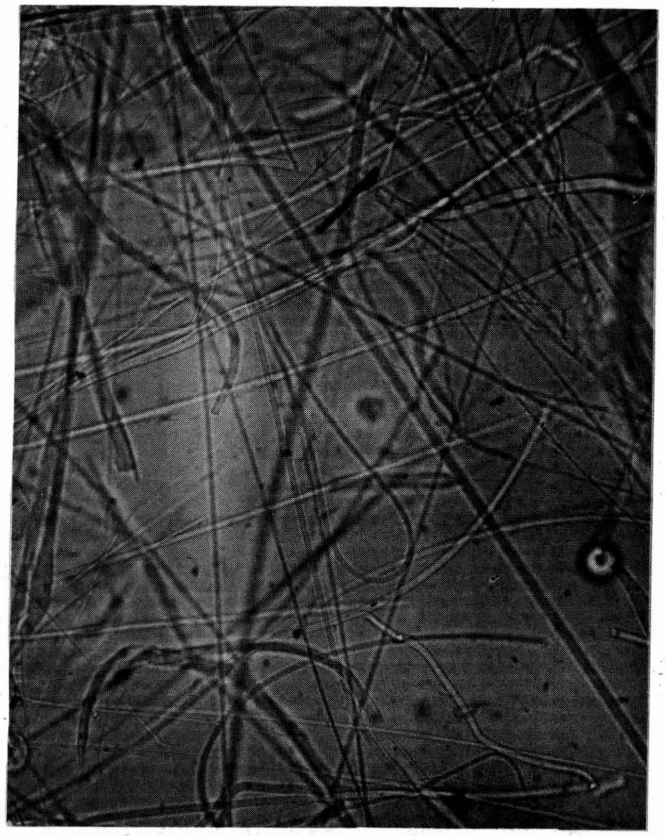

Figure 6B

Magnification 125X

Wool fibre produced from charge containing 45 per cent Beauce Co. Sands.

The diameters of a number of fibres which were measured are shown in Table 14.

TABLE 14

Fibre Diameter of Mineral Wool

Amount of Beauce Co. Sand Added - Per Cent	Range of Fibre Diameter in Sample -μm (μ)	Median Diameter μm (μ)
35	1 to 9	3.8
40	2 to 7	4.5
45	4 to 13	7.5
50	4 to 15	4.0

Both the fibre diameter and the shot content, which is less than 30 per cent, fall within the range considered by U.S. Bureau of Mines, to be of good quality. No sulphur is expected to be present. The colour of the mineral wool is good, ranging from an off-white to a white-light blue with the off-white predominating. Under the conditions of the tests, there was only moderate control of the air pressure, pour height, and temperature of the melt; consequently, good control of the fibre diameter was not possible but good-quality fibre was produced. Better control of the conditions would very likely render fibre diameter predictable and even improve the wool.

Other materials such as ground waste glass could be added to asbestos tailings for mineral wool manufacture. An added bonus in this case would be lower melting temperature and, consequently, lower cost of production.

The effect of melt viscosity on fibre diameter has been discussed by Turkdogan[10]. Other operating conditions such as height of drop of liquid, air pressure, air flow contact angle also would have large effects, which would have to be determined by pilot plant tests.

Buttons of nickeliferous iron were found in the cooled melt. Two of these were analyzed by X-ray fluorescence and contained 5.8 and 6.8 per cent nickel. A market is said to exist for such material[13].

CONCLUSIONS

A good quality wool can be made by blowing a melt of asbestos tailings and a local sand from the Eastern Townships of Quebec. Ferro-Nickel containing 5 to 6 per cent nickel is a by-product.

Preliminary capital costing of this process (See Appendix) suggests that it could be a viable operation, returning over 20 per cent on investment before taxes. The sale of the nickeliferous by-product could be credited to process costs.

Further development work and more extensive market analysis are required. Pilot plant studies are believed to be warranted to firm up technical and economic considerations such as process design, equipment, product yields, and by-product.

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AW/HSW/am

APPENDIX

MARKET ESTIMATE

Total new building in 1972* in the region east of the Manitoba-Ontario border amounted to $5,592 million. The Quebec proportion amounted to $1,838 million or 32.9 per cent. The building types include industrial, residential, commercial, and institutional. On the basis of individual types, the Quebec proportion varied between 30.4 and 34.7 per cent. Quebec's proportion was similar in 1971-70. For the following market calculations, the Quebec proportion has been conservatively estimated at 30 per cent.

It is assumed that the volume of mineral wool insulation consumed in Quebec would be in the same proportion for any one year to Quebec's proportion of new building construction, i.e., 30 per cent of the total.

For 1972, the total quantity of mineral wool insulation shipped in batt form** to the region east of the Manitoba-Ontario border is estimated at 153×10^6 cu ft***. Thirty per cent of this quantity (Quebec's proportion) amounts to $0.30 \times 153 \times 10^6 = 46 \times 10^6$ cu ft. On the assumption that a new plant would secure ten per cent of this market, this would amount to sales of batt wool = 4.6×10^6 cu ft.

Quebec's proportion of loose and granulated wool was estimated to amount to 5.1×10^6 cu ft. Assuming conservative densities (lb/ft^3) of 0.5 for batts and 4 for loose wool, the projected capacity is:

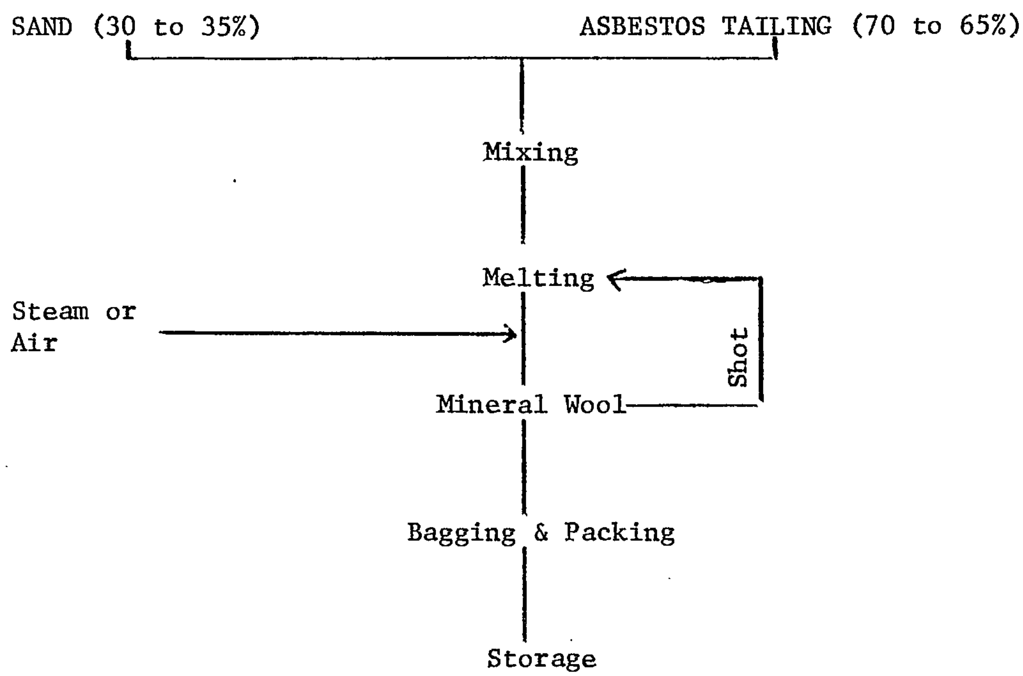
batts	$4.6 \times 10^6 \times 0.5$	$= 2.3 \times 10^6$ lb
loose and granulated	$5.1 \times 10^6 \times 4$	$= 20.4 \times 10^6$ lb
	Total	22×10^6 lb

* Statistics Canada, Cat. No. 64-201, "Construction in Canada" (1970-72).
** These consist of grades R7, 8, 10, 12, 14 and 20.
*** Statistics Canada, Cat. No. 44-004, "Mineral Wool", Dec. (1972).

ECONOMIC EVALUATION

Market Survey & Plant Capacity

SCHEMATIC FLOWSHEET



CAPITAL COST

Capital Cost of Proposed Plant

The proposed production is 22,000,000 lb/year.

The U.S.B.M. plant[12] is rated at 38,350,000 lb at a capital cost of $2,294,270.

Using the 0.6 factor for comparison of plant capacity, the cost of the new plant is calculated as follows:

$$Cn = r^{0.6} C$$

and $\log Cn = 0.6 \log r + \log C$

where: Cn = proposed plant cost
r = ratio of proposed to original capacity
C = previous plant cost

Cost of new plant = $1,643,700

Fixed Capital

manufacture of mineral wool	$1,643,700
plant facilities 4% of above	65,700
plant utilities 2% " "	32,800
Fixed capital cost	$1,742,200

Working Capital Cost at 10% of Fixed Capital*	174,200
Total Capital Cost	$1,916,400

Operating Costs

assume 250 days operation annually
annual sales of $1,000,000
plant output 22,000,000 lb/yr

Direct Cost (annual)

Raw materials
Tailings asbestos (no costs assigned)

Sand 30% of total tonnage	\$ 6,600
Bags @ 0.10/bag (40 lb/bag)	55,000
	\$61,600

Utilities

Fuel and Electricity
(a) breakdown based on Canadian Statistics = \$60,000
(b) based on U.S.B.M. plant =
$\frac{22 \times 10^6}{38 \times 10^6} \times \$141,000 = \$81,631$

use higher figure — \$ 81,631

Direct Labour

Requirements based on the following:		total
materials handling	- 1 man/1 shift	1
furnace	- 2 men/3 shifts	6
wool-room	- 1 man/1 shift	1
bagging and product handling	- 3 men/1 shift	3
		11

Labour @ \$3.50/hr and
supervision @\$12,000 annualy,
based on U.S.B.M.[12] \$144,000 for 17 men,

labour = $\frac{11}{17} \times \$144,000 =$	\$ 93,176
Supervision	12,000
Payroll	\$105,176

Plant Maintenance, 4% of Fixed Capital[15] — \$ 72,000

Payroll Overhead - 25% of payroll plus maintenance less material

assume material = \$20,000	
then maintenance less material = \$52,000	
therefore 0.25 (105,176 + 52,000) =	\$ 39,300
operating supplies = 20% of plant maintenance = 0.20 x 72,000 =	14,400
	\$ 53,740

Indirect Cost, 40 per cent of direct labor and maintenance

0.40 ($105,200 + 72,000) = 0.40 x 177,200 $ 70,880

Fixed Cost

Taxes, 1 per cent of total plant cost	$ 17,422
Insurance, " " " " " "	17,422
Depreciation 15 year life	116,147
	$150,991

Summation of Costs

1. Total Capital Costs		$1,916,400
2. Operating Costs		
Direct	$374,147	
Indirect	70,880	
Fixed Costs	150,991	
Total Operating Costs (annual)		$596,018

Return on Investment (engineering method)

Annual sales (10 per cent of possible market) = 1,038,000

$$ROI = \frac{P}{C+W} = \frac{\text{annual average profit}}{\text{initial fixed capital investment plus working capital}}$$

Average profit (P) = annual sales less annual operating cost
P = $1,038,000 - 596,018 = 441,982

$$ROI = \frac{441,982}{1,742,200 + 174,200} \times 100 = \frac{441,982}{1,916,400} \times 100 = 23.1$$

If we credit the nickeliferous iron to sales (analyzed 6.8 and 5.8 per cent nickel) we obtain the following:

Nickel-iron amounts to 80 lb/ton tailings (conservatively 4% Ni) =
3.2 lb nickel/ton tailings
Cost of nickel = $1.40 lb*
Assuming no credit for the iron**
3.2 x 1.40 = $4.48/ton tailings
Assuming, conservatively, 60 per cent of mineral wool produced from tailings and 11,000 (22,000,000 lb) tons of mineral wool are produced =
0.6 x 11,000 x 4.48 = $29,700 which would be credited to sales.
Therefore, $ROI = \frac{471,683}{1,916,400} \times 100 = 24.6\%$

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* M. J. Metals Week, New York Dealer Cathode $1.40 lb.
** Private information.

If a cost of \$2.00/ton were charged to the asbestos tailings, this would add to the direct cost for raw materials of $\frac{70}{30} \times 6600 = \$15,400$ annually.

and $ROI = \frac{1,038,000 - (596,018 + 15,400)}{1,916,400} \times 100 = 22.2\%$

The sale of the nickeliferous iron, if nothing else, can be used to cover other costs such as asbestos tailings.