TECHNICAL NOTE

THE BENEFICIATION STUDIES OF GARNET DEPOSITS FROM KOHE-E-GABRI AREA OF IRAN

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Abstract The occurrences of huge reserves of garnet deposits have been reported from different parts of Iran specially those of Kohe-E-Gabri area which is very high grade in nature. These deposits can not be directly used as abrasives, filter aid and many others because of some impurities present. To know the mineralogical composition, the type of garnet, the shape of the particles, the chemical character and the mesh of the grind all of which play a vital role in finding out suitable flowsheet design, the samples have been subjected to detailed mineralogical and microscopic studies, sieve analysis, liberation studies and chemical analysis. The results indicate that, the type of garnet is anderadite with relative grade of 75% and most of the particles shape are of edged type rather than rounded one and this is to be taken in to account while using them as abrasives and filter aids. Quartz, Calcite, Wollastonite, Magnetite and Hematite are the impurities present in the order of abundance and liberation studies show that the optimum mesh of the grind is about 600 microns. Based on the characterization studies, it was suggested that the gravity and magnetic methods would be the suitable separation techniques for removing the impurities. Therefore, the beneficiation studies have been carried out with, table, spiral, multigravity and magnetic separators. In all gravity techniques due to higher specific gravity of magnetite, this particular mineral has been separated with garnet in concentrate which is removed later with a magnetic separator. Finally based on the preliminary characterization and beneficiation studies, it is possible to upgrade the garnet deposits of Rafsanjan area to the tune of more than 95% garnet with recovery of above 87%. The results obtained are not only encouraging but also form original and distinct contribution to the beneficiation of garnet in general, and to that of Kohe-E-Gabri area in particular.

Key Words Garnet, Table, Spiral Magnetic Sparation, Multi Gravity Separation, Kohe-E- Gabri

چکیده ذخائر بزرگی از گرونا در نقاط مختلف ایران از جمله منطقه کوه گبری رفسنجان گزارش شده است که از لحاظ عیار نیز قابل توجه می باشد. گرونای این منطقه به دلیل وجود ناخالصی های همراه مستقیماً قابل کاربرد در صنایع ساینده ، تصفیه آب و دیگر صنایع نمی باشد. به منظور دستیابی به ترکیبات کانی شناختی، نوع گرونا، خواص شیمیائی و حد بهینه خردایش که از پارامترهای موثر در طراحی فلوشیت گرونا می باشد، نمونه، مورد مطالعات عمقی میکروسکوپی، کانی شناسی، تجزیه ابعادی و شیمیائی و تعیین درجه آزادی قرار گرفته است. نتایج بدست آمده نوع گرونای منطقه را اندرادیت با عیار تقریبی ۷۵ درصد تعیین نمود که ذرات آن از نظر شکل گوشه دار بوده و لذا از دیدگاه کاربرد در صنایع ساینده و تصفیه آب از اهمیت خاصی برخوردار می باشد. ناخالصیهای همراه شامل کوارتز، کلسیت، ولاستونیت، مگنتیت و هماتیت می باشد. مطالعات تعیین درجهٔ آزادی نیز حد بهینهٔ خردایش را در حدود ۶۰۰ میکرون مشخص نموده است. با توجه به مسائل عنوان شده پیش بینی گردید که بتوان ناخالصیهای همراه را با روش های نقلی و یا مغناطیسی از گرونا جدا نمود. بنابراین عملیات فرآوری توسط جیک، میزلرزان، اسپیرال جداکننده مغناطیسی تر و خشک و همچنین میز نرمه موزلی (مولتی گراویتی) دنبال گردید. در کلیه روشهای نقلی به دلیل جرم مخصوص زیاد منیمیت، این کانی به بخش کنسانتره منتقل گردیده و سپس توسط جداکننده مغناطیسی جدا گردیده است. در خاتمه با توجه به مطالعات مقدماتی و تکمیلی می توان کنسانتره ای با عیار بیش از ۹۵ درصد گرونا و بازیابی بیش از ۸۷ درصد را تولید نمود

INTRODUCTION

Garnet is a general name for a family of complex silicate minerals having similar physical properties, crystal forms and general chemical forms, and general chemcial formula, $A_3B_2(SiO_4)_3$ where the A site houses Ca, Mg, Fe^{2+} or Mn^{2+} and the B site incorporates Al, Fe^{3+}, and Cr^{3+}. They crystallize in the hexoctahedral class of the isometric system and are similar in crystal habit [1,2].

The Mohs hardness of garnet varies from 6.5 to 9 [3]. However, if the crystal is crossed by incipient fracture planes, or if it contains inclusions of other minerals, the useful hardness may be much lower [4]. As with hardness, the specific gravity of garnet varies considerably which may be as low as 3.2 or as high as 4.3 (g/cm^3) depending on the chemical composition which is the most important physical property controlling the behavior of major and minor minerals during the concentration process [3].

There is no definitive method for testing the quality of garnet or any other loose-grain abrasive except by actual application. For example specifications for filtration involve garnet's particle shape, specific gravity, effective grain size, coefficient of grain size uniformity, content of acid-soluble impurities, and content of radioactive and heavy metals. The sale of garnet for sandblasting, water filtration, and abrasive is by screen size. In sandblasting the most widely used size is -1 + 0.3 and -0.5 + 0.21*mm*, in multimedia water filtration systems is -4.75+1.41 and -0.84+0.3*mm* and in abrasive cutting applications it is -0.25+0.177*mm* which may account for 90% of the garnet used. The type of garnet is also of paramount importance. For example most garnet used in abrasive applications is either the almandite or almandite-pyrope. It should be present in the deposits as discrete crystals that are at least 6 to 13*mm* in size and that are liberated when the ore is crushed to -2*mm*. The crystals should be free from any inclusions, such as quartz, mica, hornblende, feldspar and pyroxene, magnetite, pyrite and ilmenite. It should also be free of alteration, uniform in hardness and density. It should not be, however, badly weathered or highly friable.

But the garnet deposits of Kohe-E-Gabir area which is situated in the East of Rafsanjan city with very huge reserve lack the above specifications and thus, needs characterization studies which play a vital role in finding out suitable beneficiation techniques.

The garnet deposit of this area has been subjected to detailed geological, mineralogical and chemical analyses. It was found that the major zone in the area is garnetite with a depth of 25 meters of which most constituent minerals are garnet with an average grade of 70-100% andratite and grossularite as a basic consituent minerals which are in the form of very fine and coarse grains up to 6*cm*[5]. Based on the preliminary investigations carried out, it was found out that for this type of deposits which are similar to those in U. S. A [2]. The gravity and magnetic method would be suitable separation techniques for removing the impurities like quartz calcite, wollastonite, magnetite and hematite.

The garnet deposits of Kohe-E-Gabri area have not been subjected to, as yet, systematic benefication studies. Therefore, the detailed beneficiation studies have been carried out by the author. This paper deals with the characterization and beneficiation studies. The results obtained are not only encouraging but also form original distinct contribution to the beneficiation process in general, and to that of Kohe-E-Gabri area in particular.

EXPERIMENTAL METHODS

Sample Preparation

A part of the bulk sample (500*kgs*) received was subjected to size reduction very carefully in a jaw and cone crusher in closed circuit with a single deck screen to give a crushed product of -2360 microns. The sampling techniques similar to those of Jones riffles and Coning and quartering methods were adopted and representative samples were prepared for further studies.

Chemical Analysis

The sample for head assay was obtained by coning and quartering and rotary sampler. The product was ground in an electric pulverizer machine to obtain a product of -100 mesh size and kept in an oven at constant temperature (105°*C*) for 5 hours. the results of chemical analysis are tabulated in Table 1.

For comparative studies and in order to identify the type of the garnet, a small amount of pure garnet obtained by conventional Sink and float test and subjected to chemical analysis the results of which are tabulated in Table1.

X-Ray Diffraction Studies

X-ray diffraction is not only used for identification of minerals and their crystalline character but also for assessing the abundance of each mineral phase in multiple mixture.

In order to identify the type of the garnet and mineral constituents of the sample, the powder X-Ray diffractogrammes have been obtained for the sample ground to -200 mesh employing a Phillips powder diffraction unit (Table 2). From the XRD studies and the information from Table 1, it can be figured out that the type of garnet is anderadite and other minerals are calcite, magnetite, wollastonite and quartz in the order of abundances.

TABLE 1. Chemical Analysis of Garnet Sample.

Constituents	Weight%	
	impure	pure
CaO	35	33.4
SiO_2	34.6	37
Fe_2O_3	22	25.2
Al_2O_3	2.08	2.41
MgO	0.82	0.5
MnO	0.2	0.14
K_2O	0.072	0.027
SO_3	0.05	0.028
P_2O_5	0.03	0.012
L.O.I	3.49	0.27
others	1.66	1.013

Petrographic Studies

In beneficiation studies the petrographic investigations play an important role. It is more so when ore and gangue minerals are transparent. In this study, it is not only possible to know the volumetric proportion of the ore and the gangue mineral, the deciding factor of the grade of ore, but also other characters, like grain size, shape, texture and intergrown which are equally important in the beneficiation studies. The thin sections of the garnet are prepared and subjected to petrographic studies. The modal proportion and grain size of the minerals (average 15 thin sections) are given in Table 3 and microphotographs are also illustrated in Figures 1 and 2.

The types of the garnet and their respective

TABLE 2. Type of the Mineral with Respect to 2θ and d (XRD Analysis).

S. No.	2θ	d	type of mineral
1	26.7	3.34	Quartz
2	26.8	3.31	Wollastonite
3	29.5	3.03	Calcite
4	33.3	2.69	Anderadite
5	35.49	2.53	Magnetite

TABLE 3. The Modal Analysis and Grain Size of the Constituents Mineral.

S. No.	mineral	modal Percentage	Grain size (microns)
1	garnet	75	300-400
2	calcite	7	400-500
3	quartz	5	10-15
4	wollastonite	6	100-150
5	magnetite and hematite	7	200-300 10-15

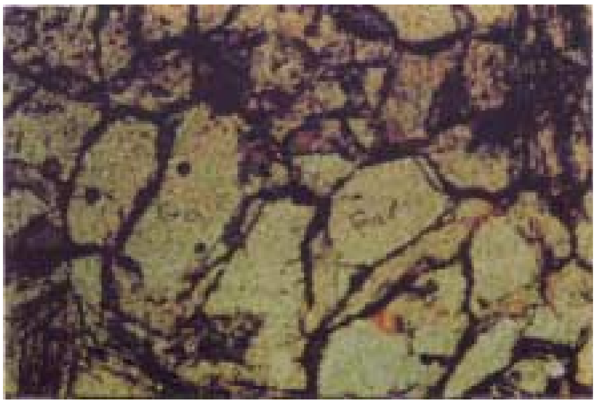

Figure 1. Microphotograph × 50. The black grains are garnet which are oxidised at the boundaries. The white plane is garnet.

proportion are also tabulated in Table 4.

The microscopic studies reveals that most of the constituent minerals is garnet (Anderadite) which is inter locked with magnetite and wollastonite. It seems that if the sample is ground to less than 500 microns, garnet can be liberated from these impurities, though, it has to be confirmed by further liberation studies.

Preparation of Standard for Assay Analysis

Since the chemical formula of all garnets varies with different constituent elements on the one hand, and presence of such elements at the same time in their matrix on the other the grade (percentage) of garnet can not be determined by conventional chemical analysis. On the account of this preliminary study a standard curve was prepared with the mixture of known percentage of pure garnet and impurities. (for higher accurasy, 10% of fluorite is added to each sample before XRD analysis). The ratio of pick (under curve/area) of garnet to that of fluorite was the main basis of analysis. Table 5 shows these ratios with respect to different grades of garnet and Figure 3 shows the standard curve. The equation of such curve is written as below:

$$G = 31.899Y + 8.58$$

TABLE 4. Types of the Garnet.

S. No	Type of the mineral	percentage
1	Andradite	90
2	Grossularite	7
3	Almandite	1-2
4	Pyrope	1
5	Spessartite	<1

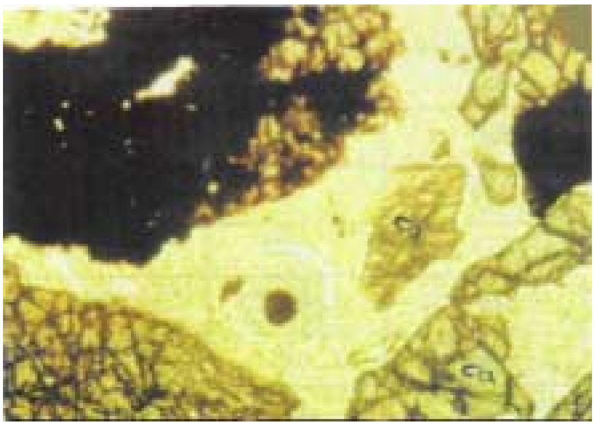

Figure 2. Microphotograph × 50. The black grains are magnetite and calcite is also present as impurities.

TABLE 5. Different Pick Ratios with Respect to Different Grades.

S. No.	Ratio of picks	garnet grade (%)
1	0.85	35.5
2	1.25	42.79
3	1.18	48.3
4	1.36	55.43
5	1.69	63.11
6	1.85	71.39
7	2.15	78.24
8	2.7	90

Where:

$Y = A_1/A_2$

A_1= area for garnet pick

A_2= area for fluorite pick

G = Grade of garnet (%)

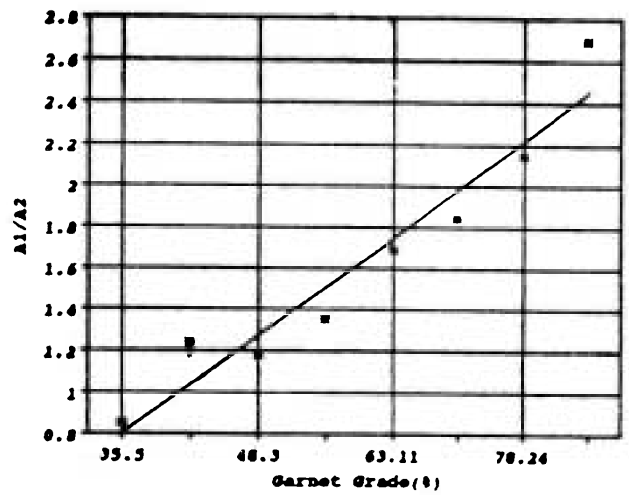

Figure 3. Standard curve for assay analysis.

The value of the (G) is the percentage of garnet before addition of fluorite.

Particle Size Analysis

Particle size analysis is used in beneficiation studies both to determine the efficiency of comminution equipment and to develop a yardstick for assessing the degree of ground product to know the optimum liberation size.

The representative sample has been subjected to particle size analysis and the resutls are shown in Figure 4. Figure 4 shows that more than 80% of the sample is finer than 1900 microns, and 50% of the sample is finer than 1140 microns. The distribution of garnet in (-1000+500) and (-2000+1400) micron is much higher than in other fractions. This is to be taken in to account and should be confirmed by liberation studies.

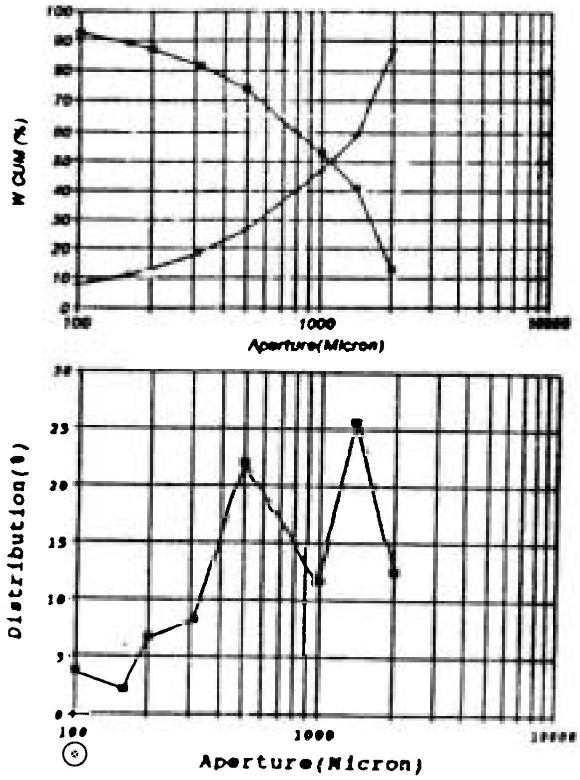

Figure 4. Size distribution plots for garnet sample.

Liberation Studies

In order to determine the degree of liberation and the size at which the garnet gets free from other impurities, the sample was subjected to grain counting (Figure 5) and further confirmed with sink and float tests using bromoform (2.89) diiodo methane (3.32) and malonate formate (4.03) g/cm^3.

The counting method clearly shows that 80% of the garnet can be liberated below 630 microns. The sink and float tests were carried out on sieve fractions, (-1000 +700), (-700+500) and (-500 +315) microns using the said liquids. The results are shown in Figure 6.

Figure 6 clearly shows that as the size of the particle decreases upto 500 microns while the proportion of garnet increases specially in liquid fraction with Sp. Gr 3.32 g/cm^3

BENEFICIATION BASED ON CHARACTERIZATION STUDIES

With respect to preliminary studies and due to specific gravity difference between anderadite (3.8) and other gangue minerals like wollastonite (2.8), magnetite (5), quartz (2.65), calcite (2.72) and hematite (4.5) on the one hand and magnetic property difference between anderadite (paramagnetic) and other gangue minerals (magnetite feramagnetic, calcite diamagnetic and hematite paramagnetic) on the other, it is possible to upgrade such type of deposits with gravity and magnetic separation techniques.

Therefore the beneficiation studies have been carried out in two parts. One part deals with jigging and tabling through magnetic separations on sieve fractions -2360 +1000 and -1000 microns respectively without success due to interlock between garnet and other associated gangue minerals. The results of this part of investigation is tabulated in Table 6 and the overall flowsheet is illustrated in Figure 7. The second part is deals with tabling, spiral and multigravity followed by low magnetic separation and low and high magnetic separations. In all gravity techniques the magnetite is separated in concentrate portion along with garnet due to its high sepecific gravity which has been removed

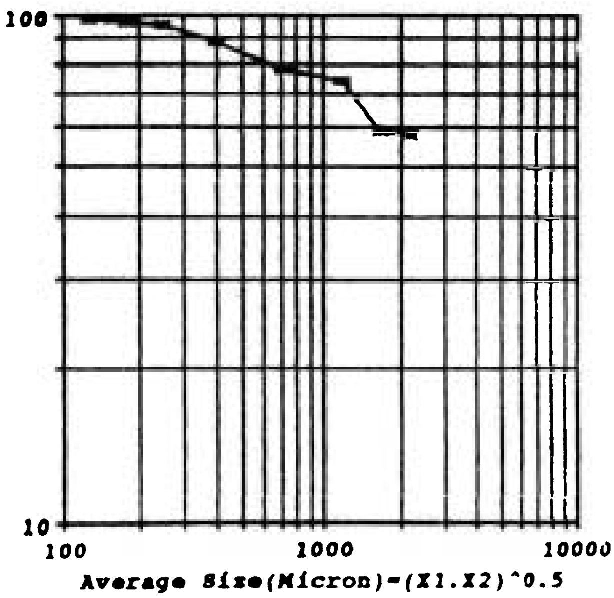

Figure 5. Determination of degree of liberation by counting method.

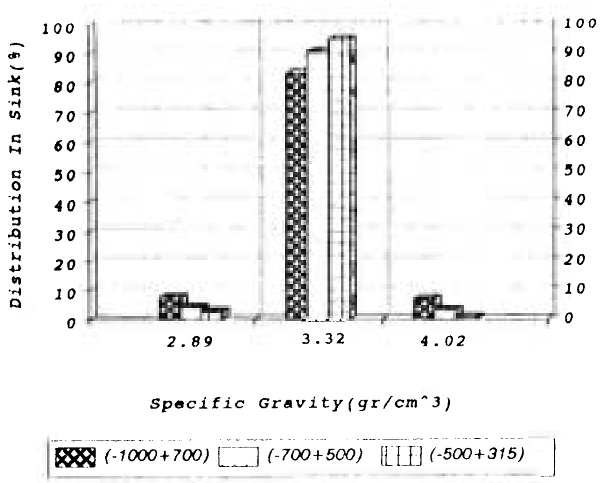

Figure 6. Distribution of garnet as a function for Sp. Gr of heavy liquid in sink portion.

TABLE 6. Results of Gravity and Magnetic Separations.

Method	Grain size distribution (micron)	product	weight (%)	Assay (%)	Recovery (%)
Jigging	-2360+1000	C T tot,	43.41 56.59 100	82.18 100 74.13	48.12 51.88 100
	-2360+2000	C T tot.	31.8 68.2 100	86 66.06 72.4	37.77 62.23 100
	-2000+1400	C T tot.	58.18 41.82 100	87.33 57.31 74.77	67.94 32.06 100
	-1400+1000	C T tot.	58.18 41.82 100.00	87.33 57.31 74.77	67.94 32.00 100.00
	-1000+149	C T tot.	55.58 44.42 100	95.37 57.03 78.33	67.66 32.34 100
Wedage tabling and L.I.M.S.	-1000+710	C T tot.	56.14 43.86 100	89.82 63.12 78.11	64.55 35.45 100
	-710+500	C T tot.	70.37 29.63 100	96.78 50.99 83.19	81.84 18.16 100
	-500+250	C T tot.	62.96 37.04 100	95.72 62.04 83.23	72.39 27.61 100
	-250+149	C T tot.	71.86 28.14 100	96.06 54.13 84.25	81.92 18.08 100
	-149+37	C T tot.	52.23 47.77 100	98.25 59.27 79.63	64.44 35.56 100

further through low magnetic separation. The results obtained are tabulated in Table 7 and the flowsheet is illustrated in Figure 8.

RESUTLS AND DISCUSSION

Gravity and Low Magnetic Separations

The results obtained from gravity separation (Jigging) on coarse fraction (-2360 +1000 microns) were not promising due to unliberated garnet from other gangue minerals. However, on finer size fraction (-1000μ) with tabling followed by dry low magnetic separation, results were somehow better comparatively, but not to the specification required. Finely disseminated gangue minerals with garnet could be responsible for such results (Table 6).

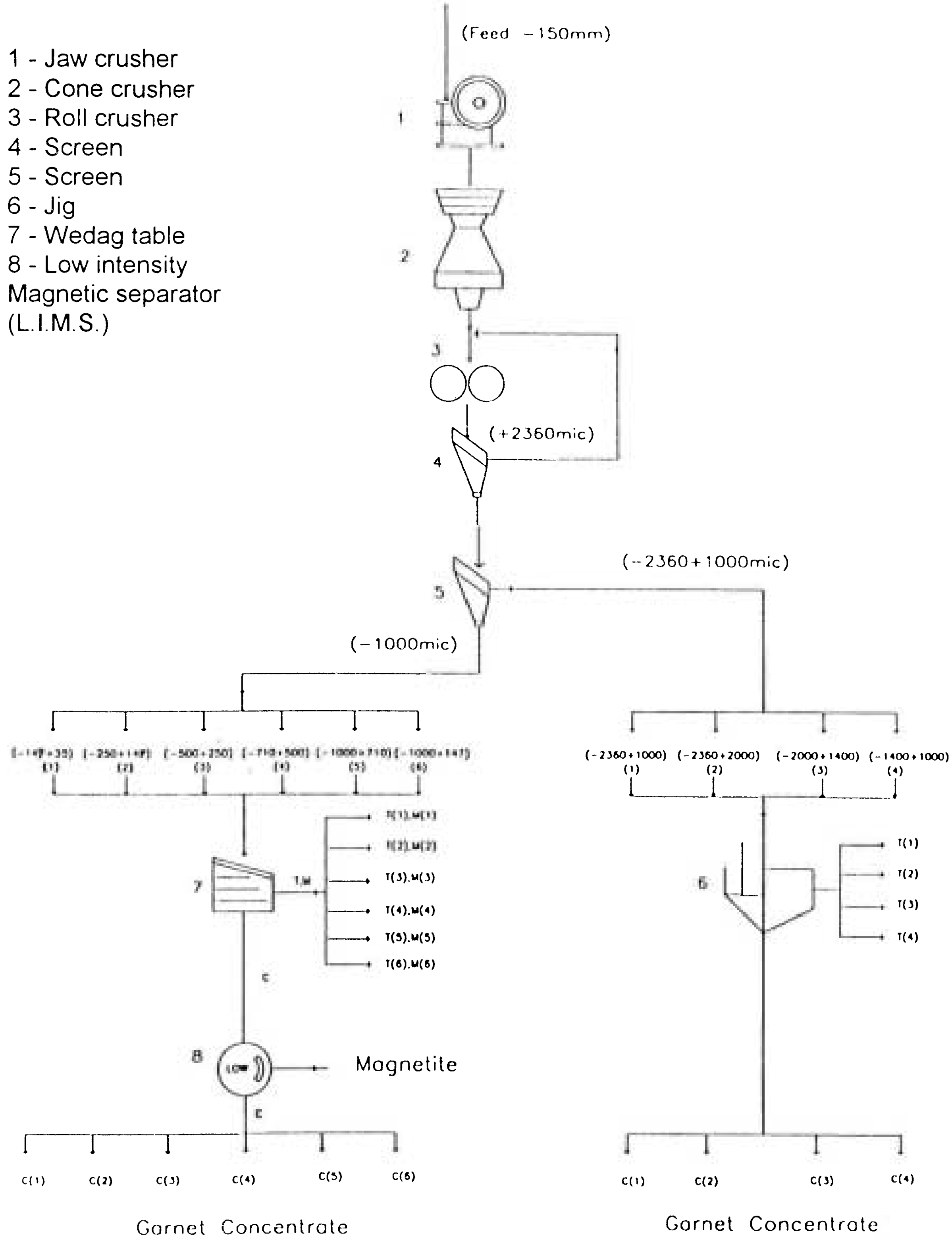

Figure 7. Flowsheet based on jigging and tabling followed by magnetic separation.

1- Jaw crusher
2 - Cone crusher
3 - Roll crusher
4 - M.G.S.
(Multigravity sep.)
6 - L.I.M.S.
Low intensity mag. sep.
7 - Wilfley table (Rogher)
8 - Wilfley table (cleaner)
(L.I.M.S.)
9 - L.I.M.S.
10 - Humphreys spiral
11 - L.I.M.S.
12 - L.I.M.S.
13 - H.I.M.S.
(High intensity mag. sep.)
14 - L.I.M.S.
15 - L.I.M.S.

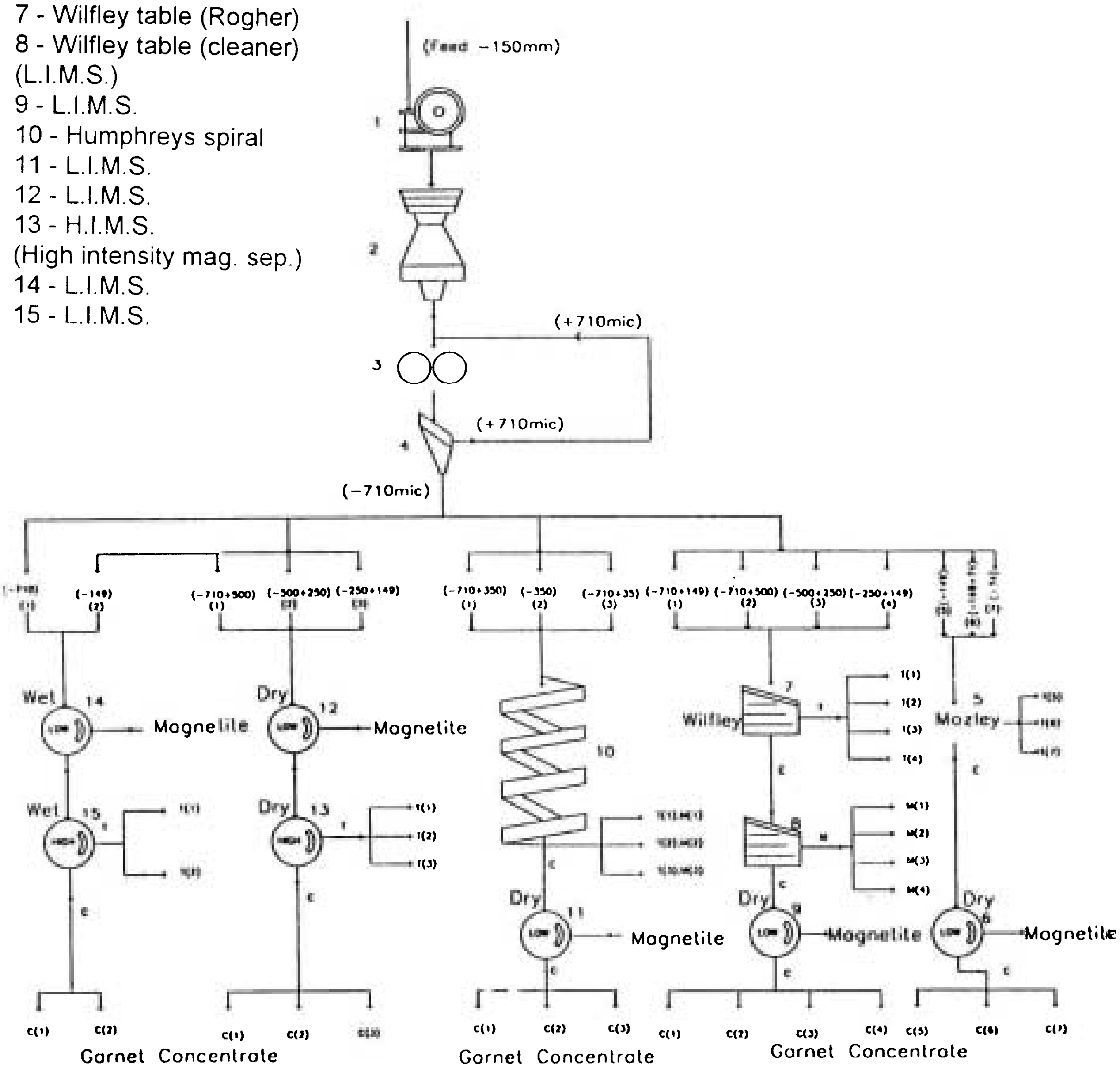

Figure 8. Final flowsheet based on optimum combination techniques.

Combination of Gravity and Magnetic Separations

This part of investigation is carried out on sample reduced to -710 microns. The results of this part of investigation are tabulated in Table 7. As already

TABLE 7. Results of combination of Gravity and Magnetic separations

Method	Grain size distribution (micron)	product	weight (%)	Assay (%)	Recovery (%)
wil fley table +L.I. M.S.	-710+500	C	77.08	95.77	90.46
		T	22.92	33.95	9.54
		tot,	100	81.6	100
	-500+250	C	76.27	95.12	85.65
		T	23.73	51.21	14.35
		tot.	100	84.69	100
	-250+149	C	65.29	98.25	76.48
		T	34.71	56.85	23.52
		tot.	100	83.88	100
	-710+149	C	73.99	94.65	87.89
		T	26.01	37.11	12.11
		tot.	100	79.68	100
Dry Magnetic Separator (L.I.+H.I)	-710+500	C	87.08	88.46	97
		T_1*	8.61	24.28	2.63
		T_2*	4.31	6.7	0.36
		tot.	100	79.41	100
	-500+250	C	84.93	95.56	94.64
		T_1*	11.77	36.96	5.07
		T_2*	3.3	7.54	0.29
		tot.	100	85.76	100
	-250+149	C	80.73	94.04	91.21
		T_1*	13.62	40.55	6.64
		T_2*	5.65	31.7	2.15
		tot.	100	83.23	100
Humphreys Spiral + L.I.M.S	-710+37	C	79.01	87.45	89.66
		T	20.99	37.95	10.34
		tot.	100	77.06	100
	-710+350	C	81.09	88.57	91.89
		T	18.91	33.52	8.11
		tot.	100	78.16	100
	-350	C	68.77	92.78	77.51
		T	31.23	59.29	22.49
		tot.	100	82.32	100
Wet Magnetic Separater (L.I+H.I)	-149	C	49.06	96.23	60.42
		T_1*	47.13	63.19	38.11
		T_2*	3.81	30.11	1.47
		tot.	100	78.14	100
	-710	C	81.57	90.44	95.42
		T_1*	13.5	20.73	3.62
		T_2*	4.93	15	0.96
		tot.	100	77.31	100
Mazley Table + L.I.M.S	-149+74	C	60.52	97.2	73.48
		T	39.48	53.76	26.52
		tot.	100	80.05	100
	-74	C	46.07	97.8	59.23
		T	53.93	57.5	40.77
		tot.	100	76.7	100
	-149	C	71.65	96	85.61
		T	28.35	40.77	14.39
		tot.	100	80.34	100

* T_1: Diamagnetic material
* T_2: Feromagnetic material

mentioned, due to high specific gravity of magnetite, this particular mineral was separated with garnet. Therefore in all gravity techniques applied, concentrate was subjected to low magnetic separation to reduce the content of magnetite in the concentrate.

The results of combination of this part of investigation is shown in Table 8. From this table, high grade and recovery for garnet respectively (95.35 and 90.13%) but from economic point of view, the second column in the table is selected as the final and optimum result. The proposed flowsheet is also illustrated in Figure 9.

CONCLUSIONS

The following conclusions can be drawn from this investigation:

The garnet deposit of Kohe-E-Gabri area has been subjected to characterization studies. It was found that the type of the garnet is anderadite with relative grade of 75%. It was also found that most of the particles shape are edged type rather than rounded one which should be taken into account while using them as abrasives and filter aids.

Quartz, calcite, wollastonite, magnetite and hematite are the impurities present in the order of aboundences. Liberation studies, show that optimum mesh of grind is around 600 microns which has been confirmed with counting method and sink and float tests.

Based on characterization studies and the nature of the constituent minerals, it is possible to upgrade such type of deposits with gravity and magnetic, separations especially with combination of tabling and low magnetic separation on seive sizes of -710 + 149 microns, dry low magnetic separation on two fractions (-500+250 and -250 + 149 microns) and finallly with MGS and low Magnetic separation on 149 microns.

TABLE 8. Final Results Based on Optimum Combination Techniques.

No.	Combination of methods	product	weight (%)	grade (%)	Recovery (%)
1	Wilfley table and L.I.M.S. (-710+500) + L.I.M.S. and H.I.M.S (-500 +250) +L.I.M.S. and H.I.M.S (-250+ 149) + Mozley table and L.I.M.S. (-149)	C T	78.05 21.95	95.35 37.13	90.13 9.87
2	Wilfley table and L.I.M.S (-710+149) +Mozley table and L.I.M.S. (-149)	C T	73.23 26.77	95.08 38.38	87.14 12.86
3	Wilfley table and L.I.M.S. (-710+149) + L.I.M.S and H.I.M.S. (-149)	C T	65.83 34.17	95.04 48.62	79.01 20.99
4	Wilfley table and L.I.M.S (-710 +149)	C T	49.78 50.22	94.62 65.05	59 41

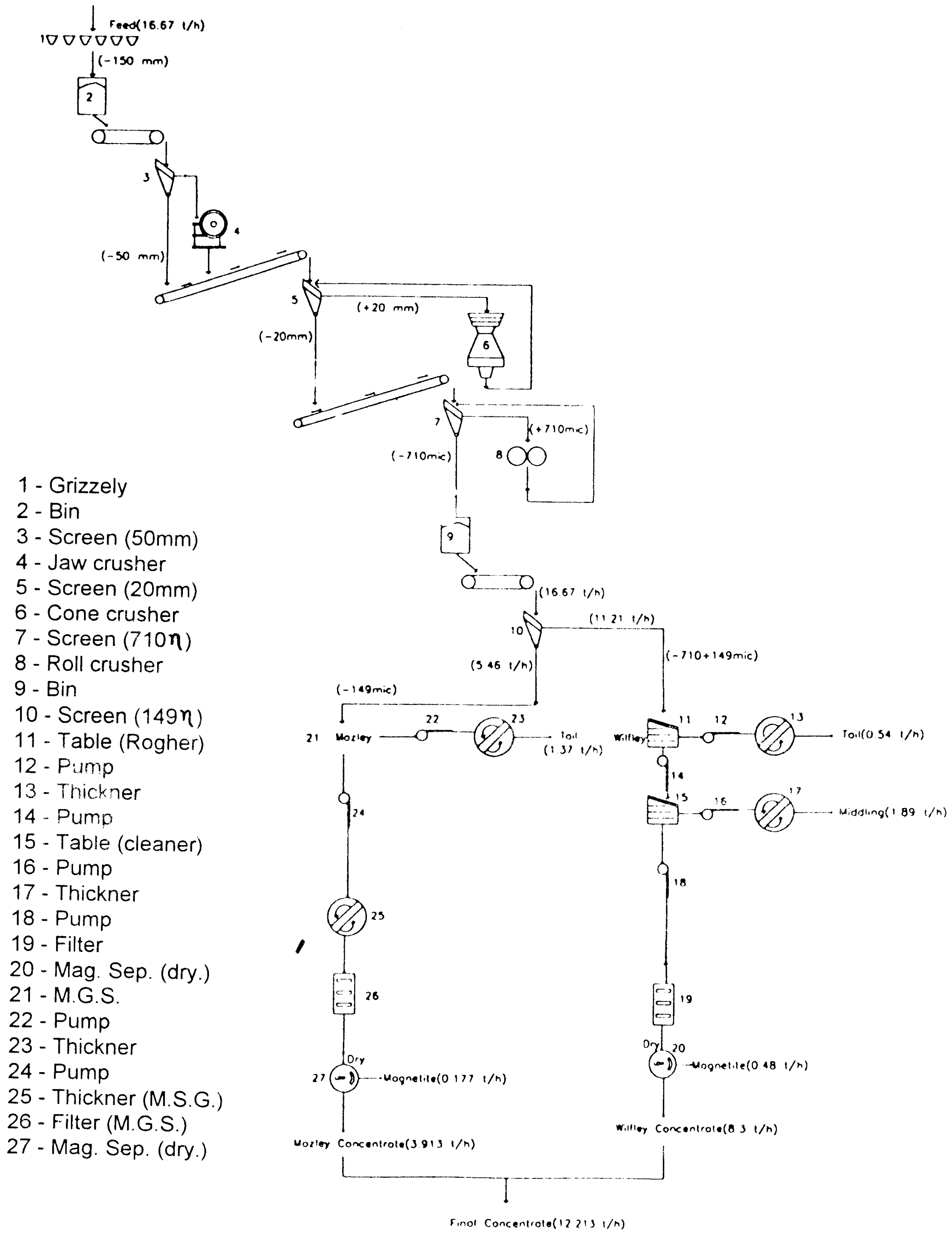

Figure 9. Final flowsheet based on optimum combination techniques.

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