# The Studies of Garnet Deposits of Iran
# from Industrial Application Point of View

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## *Abstract*

*Garnet is a natural abrasive industrial mineral which produced by four producer In three
countries. Garnets include igneous Rocks have formed under metamorphosed and limestone
foliated . The most important of the garnet deposits of Iran is located in Koh-E-Gabri ,
Hamadan and Sangbast in  Mashhad .In Iran Garnet is sold about 187$/t, , but the range of
price in other countries is approximately 160-280$/t.  The information about Import and
Export and determining the real price of Garnet in Iran is not available definitely. According
to the economical and engineering evaluation accomplished on Garnets mine of Iran ,it  shows
that this mine with greatest Rate of Return ( IRR = 34 %) is one of  the  best and the most
hopeful Garnets mine in Iran. the mines such as Azandrain and Sangbast in Mashahad haven't
shown hopeful result Due to its nature.*

*Keywords: Garnet , koh_E_Gabri , Economical and Engineering ,  Abrasive, Internal, Rate of
Return .*

## INTRODUCTION

Garnet is a general name for a family of complex silicate minerals having similar physical properties ,
crystal form and general chemical forms and general chemical formula , $A3B2(SiO4)3$  where the A
site house Ca , Mg , $Fe^{2+}$ or $Mn^{2+}$ and 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 [3].

The  Mohs hardness of garnet varies from 6.5 to 9 [1]. 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.

Garnet is driven from Greek word Granatus that it was called in old precisian (Bijad) based on this
formula Garnet has three groups. [2] :

1. Al groups [Grossularite , Pyrope ,  Almandine , Spessartite ]
2. Fe groups  (Andradite)
3. Cr  groups ( Uvarovite)

Garnet is General name of minerals which they have different failure that they are used in abrasive
covers (like paper ) , in watches and electronic devises and nonabrasive concrete .

Garnets are used in grain forms for abrasive rocks and increasing friction. Generally Garnet
application is five groups:

1. Sand blasting  : the most widely used size in sandblasting is -1+0.3 and 0.5+0.21 mm
2. Water filtration: the most widely used size in water filtration is -4.75+1.41 and -0.84+0.3 mm.
3. polish

4. Jet Cutting
5. Abrasive application: the most widely used size in abrasives is -0.25+0.177 mm.

The garnet deposits of aforementioned areas with very huge reserve around Iran lack the above specification s and thus, need characterization and beneficiation studies. The garnet deposits of these areas has been subjected to detailed geological, mineralogical and chemical analysis [1] but have not been subjected to systematic beneficiation studies so far. the detailed beneficiation studies have been carried out by author and this paper deals with the characterization and beneficiation studies. The result obtained which are encouraging from the beneficiation point of view and with result of technical and economical point of view are discussed in this paper.

## PRELIMINARY STUDIES AND EXPERIMENTAL METHODS

### Sample Preparation

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

### Chemical Analysis

The sample for head assay was obtained by coning and quartering and then using a rotary sampler .It was later ground in an electric pulverizer machine to (1050 C) for 5 hours. The result of chemical analysis is tabulated in table 1.

**Table 1: Chemical Analysis of Garnet Samples**

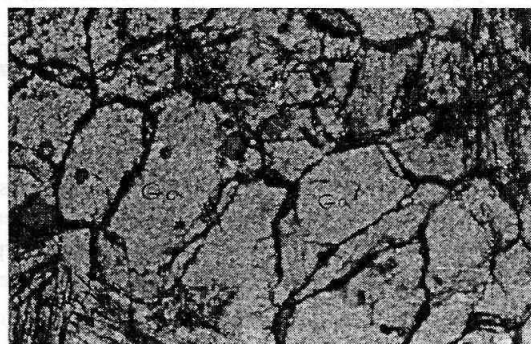| Weight % | Constituents | Weight % | Constituents |
|---|---|---|---|
| 0.027 | $K_2O$ | 37 | $SiO_2$ |
| 0.028 | $So_3$ | 33.4 | CaO |
| 0.012 | $P_2O_5$ | 25.2 | $Fe_2O_3$ |
| 0.27 | L.O.I (900° C) | 2.41 | $Al_2O_3$ |
| 1.013 | Others | 0.5 | MgO |
| 100 | total | 0.14 | MnO |



**Fig.1: Microphotographs ( *50)**
**The Black Grain are Garnet Which are Oxidized at Boundaries. The White Plane is Garnet**

### X- Ray Diffraction Studies

It is not only used for identification of minerals and their crystalline character but also for assessing the abundance of each 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 to – 200 mesh employing a Philips powder diffraction unit.

### Petrographic Studies

In beneficiation studies, petrographic investigation plays an important role. It is more so when ore and gangue minerals are transparent. Thin sections of garnet were prepared and subjected to petrographic studies. The modal proportion and grain size of the minerals are given in table 2. And microphotographs are also illustrated in Fig 1.The types of garnet and their respective proportion is also tabulated in table 3.

Table 2: Modal Analysis of the Constituent Minerals

| Magnetite and Hematite | Wollastonite | Quartz | Calcite | Garnet | mineral |
|---|---|---|---|---|---|
| 7 | 6 | 5 | 7 | 75 | Modal percentage |
| 200-300 | 100-150 | 10-15 | 400-500 | 300-400 | Grain size( microns) |

Table 3: Type of the Garnet

| Spessartite | Pyrope | Almandite | Grossularite | Andradite | mineral |
|---|---|---|---|---|---|
| 1 | 1 | 1-2 | 7 | 90 | percentage |

**Particle Size Analysis**

It is used in beneficiation both to determine the efficiency of comminution equipments and also for assessing the ground product to know the optimum liberation size.

The representative samples have been subjected to particle size analysis and the results are shown in Fig2.
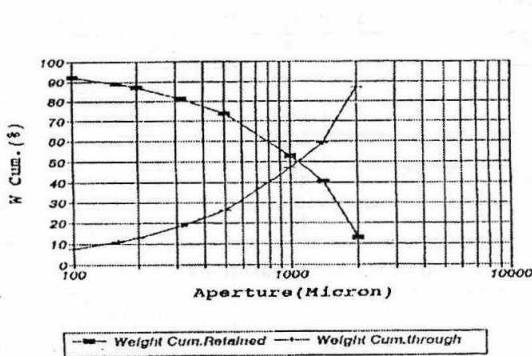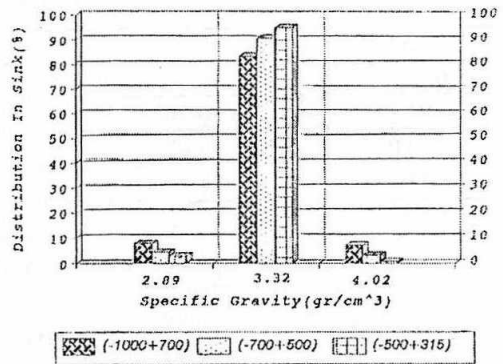


Fig. 2: Size Distribution Plot for Garnet Sample



Fig. 3: Distribution of Garnet as a Function of Sp . Gr of Heavy Liquids in Sink Protions

**Liberation Studies**

In order to determine the degree of liberation and the size at which garnet grains are liberated from other impurities the samples were subjected to grain counting and sink and float tests using bromoform (2.89) diiodo methane (3.32) and taillium malonate and formate (4.03) gr/cm$^3$ , Fig3.

**RESULT OF PRELIMINARY STUDIES**

1. The result of chemical analysis obtained show that , the type of garnet in sample ( Koh-gabri) in Rafsanjan is Anderadite with grade of 75 % .
2. The result of X-Ray obtained show that , the type of garnet in sample is andradite and other minerals are calcite , magnetite , wollastonite and quartz in order of abundances.
3. The result of Petrographic studies obtained show that , the type of garnet in sample is andradite and it is interlocked with magnetite and wollastinite .
4. The result of Particle size analysis obtained show that ,the sample is finer than 1900 microns, and 50 % of the sample is finer than 1140 microns . the distribution of garnet in fraction of (-1000+500) and (-2000+1400) micron is much higher than others.
5. The result of liberation studies obtained show that, 80 % of the garnet can liberated below 630 microns and based on Fig 3 the garnet particle are free from other material at 500 microns.

## BENEFICIATION STUDIES ON KOH- GABRI GARNET

Beneficiation tests have been carried out in two parts. One part consists of Jigging and tabling through magnetite separations on -2360+1000 micron size fraction, and the second part , to test -710 micron feed , wilfley table ,Humphreys spiral and multigravity separator, each followed by a low magnetic separation were employed or only a low and then a high magnetic separation were applied .

### Result of Beneficiation Studies

1. The result obtained from gravity separation (Jigging) on coarse fraction (-2360+1000 microns) were not promising, due to unelaborated garnet from other gangue minerals , however on finer size fraction (-1000 micron) result tabling followed by dry low magnetic separation were better table4.
2. Optimum result of beneficiation studies by Multygravity shown in table 5
3. Optimum result of beneficiation studies by high dry magnetic separator shown in table6.

Table 4: Optimum Result of Tabling and Low Magnetic Separations

| Total Recovery (%) | Grade Wedag + magnetic (%) | Grade wedag(%) | Dip of Table($^0$)))( | Grain size (microns) |
|---|---|---|---|---|
| 53.64 | 97.5 | 92.78 | 1.95 | -1000+149 |
| 64.55 | 89.8 2 | 85.4 | 2.34 | -1000+710 |
| 81.84 | 96.78 | 92.18 | 1.85 | -710+500 |
| 61.16 | 98.05 | 94.18 | 1.76 | -500+250 |
| 59.63 | 98.8 | 95.38 | 1.37 | 250+149− |
| 64.21 | 98.25 | 93.44 | 1.1 | -149+37 |

Table 5: Optimum Result of Multy Gravity and Magnetic Separations

| Recovery(%) | Grade (%) | Weight (%) | Product(%) | Grain size distribution (microns) |
|---|---|---|---|---|
| 60.52<br>39.48<br>100 | 97.2<br>53.76<br>80.05 | 60.52<br>39.48<br>100 | C<br>T<br>total | -149+74 |
| 59.23<br>40.77<br>100 | 97.8<br>57.5<br>76.07 | 46.07<br>53.9<br>100 | C<br>T<br>total | -74 |
| 85.61<br>14.93<br>100 | 95<br>40.77<br>80.34 | 71.65<br>28.35<br>100 | C<br>T<br>total | -149 |

Table 6: Optimum Result of High Dry Magnetic Separation

| Recovery (%) | Garde ( %) | Weight ( %) | RPM | Grain size (microns) |
|---|---|---|---|---|
| 97 | 88.46 | 87.08 | 50 | -710+500 |
| 94.64 | 95.56 | 84.93 | 60 | -500+250 |
| 91.21 | 94.04 | 80.73 | 60 | -250+149 |

## ECONOMIC SITUATION INVESTIGATION AND REPLACEMENT OF ABRASIVE MATERIAL IN IRAN

The price of garnet depeneding on type , quality , hardness , dimension , grain distribution , type of packeting , complicating in beneficiation operation and nearness or farness from the industrial centers , considering to these items it's price in some years was at least 60 $ /ton for low quality garnet in Sandblast and maximum 2000 $/ton for micron zed powders. Concentrate price in Iran specially in Rafsanjan was 170 and Zamanabad Hamadan 180 $/ton and other abrasives like copper and Sandblast was 150 to 212 $/ton [4]( fig4) .

Industrial abrasive market in Iran depends on imports markets, although a lot of tries have been carried out in some years for production of industrial abrasive material recently. Long distance until the end of 1981, Iran was the importer of abrasive material, but from 1989 according to the import and export information from the Iran Islamic replicas custom, export of some abrasive material has been reported, and its growth was growing year to year and this material export to other countries such as Iraq , Covet and Arabia countries..
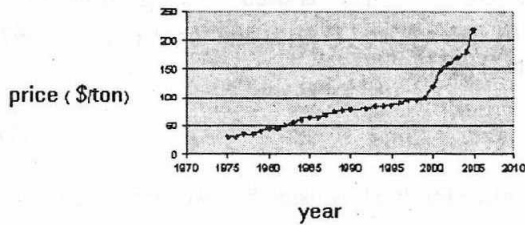
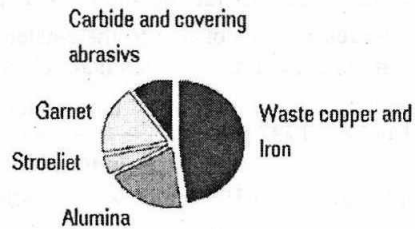

Fig. 4: Diagram of Global Price of Garnet  [4]



Fig. 5: Diagram Distribution of Different Abrasives in Iran

Generally replacement materials for garnet in Iran in sandblast include (Stroeliet , Alumina , Waste of copper , Sand , siwce in water filtration , plastic and sand siwce in abrasive of glass and lenze including Diamond , Crondom, Alumina in wood filtration and other materials aspect of abrasive powders and Covering abrasives like Carbide , Alumina oxide which these materials is used for bits of drilling and purring of Hard materials in south of Iran . Below the shape shows the facts [6] (fig5) .

In Iran despite of existence of mine like Koh- Gabri _ Rafsanjan , Zaman Abad Hamadan and Sangbast in Mashhad , garnet are imported from other countries so considering to limitation capacity of mines also lead pf necessary facilities , almost we have not any export except to some countries like Arabia and East countries. The majority uses in Iran is used in Esfahan , Tehran and Shiraz .

Today garnets for sandblast is so expensive ( 220 $/ton ) then sand price per ton is 55 to 20 $/t in the other hand considering to silica sand applications due to this fact that garnets in companion with silica sands, Has low uses also is compliable with the price of garnet to 110 $/t use that as primary material for Sandblast[7] .

## INDUSTRIAL APPLICATION OF GARNETS CONSIDERING TO ITS POTENTIAL IN IRAN

The process of converting of significant product to usable producer service for society or in the other hand in industrial or cases productional with makes to be product in cycloid production and use is economizing . Despite to high costs , time and energy , many sources which spent for the projects but an attempts with finishing the researches is filed and they are not used , however we can have the look to future with their applications and make return the investment until ten times. The ways of industrial application of projects:

1. Contouring and Revisiting for execution and after finishing of any projects , the reports must be prepared for industrial application .
2. According between executive and exports of projects
3. Clarifying the technical dimension of plan.
4. What is the benefit and application of plan?.
5. What are the capable sources of uses?
6. How will be the cooperation of the organizations and firms industrial and ete?
7. How much will be marketing costs for finding the target markets?
8. Estimating of rate of profit to costs for industrial application.
9. Estimating suitable sources.

## ECONOMIC FEASIBILITY OF FINAL SUGGESTION FLOWSHEET FOR OF KOH- E- GABRY IN RAFSANJN GARNETS

### Investment Costs

For Determine Costs of factory facilities this formula $(cost) = = a(x)^b$ is used, which a , b for 1997 has been represent . According to the existence of 2001 index price (1131.6) and index price in 1997 (1056.8) all prices will be calculated as below (formula (1))[5].

$$2001 \text{ price} = 1997 \text{ price} * \frac{\text{index price } 2001}{\text{index price } 1997} \tag{1}$$

with 9 % inflation and 1997 price we can estimate the price for 2004 by using below(formula (2))

$$\text{price } 2004 = \text{price } 2001 * (1+i)^n \tag{2}$$

which , i , n is inflation rate and project life ..

Often estimating total costs of facilities and equipment of garnet beneficiation  for factory , investment costs will be 40154513.93 $. (table7) Additional to these costs for IRR we should consider other costs which they are given below.

Table 7: Estimating Total Costs of Facilities and Equipment of Garnet Beneficiation for Factory

| Price($/ton) | Number | Description | Equipment | |
|---|---|---|---|---|
| 96341.636 | 1 | 811.61ft$^3$= Capacity | Jaw crusher | 1 |
| 214894.1 | 1 | 529.32 ( ft$^3$) = Capacity | Cone crusher | 2 |
| 419571.02 | 1 | Diameter 59.04 in | Crusher Roll | 3 |
| 9292.4 | 1 | 3.93*0.984) ft$^2$=( A | Screen | 4 |
| 163511.85 | 1 | 3.93*1.96)ft$^2$ =(A | Screen | 5 |
| 471600 | 1 | A =5.904ft$^2$ | Screen | 6 |
| 84137.13 | 1 | A =108.44ft$^2$ | Screen | 7 |
| 51181.4 | 2 | A= 36ft$^2$ | Wilfley | 8 |
| 17067.92 | 1 | Capacity= 5 ton/h | Low Magnetic separtor | 9 |
| 1134446.5 | 1 | Capacity= 5 ton/h | Low Magnetic separtor | 10 |
| 65143.96 | 1 | Diameter= 9.84 ft | Waste thickner table | 11 |
| 65143.9 | 1 | Diameter =9.84 ft | Middling thickner table | 12 |
| 98232.4 | 1 | A=107.58ft$^2$ | Filter concentrate table | 13 |
| 283273.2 | 1 | Capacity= 6 ton /h | MGS | 14 |
| 65143.9 | 1 | Diameter =9.84 ft | Thickner Waste MGS | 15 |
| 10688.7 | 1 | Diameter =19.68 ft | Thickner Concentrate MGS | 16 |

Contd…

| Price($/ton) | Number | Description | Equipment | |
|---|---|---|---|---|
| 66697 | 1 | A=59.17ft$^2$ | Filter Concentrate table | 17 |
| 13027 | 1 | 70.57 m$^3$/h=Q | Pump Thickner | 18 |
| 133108 | 1 | 105.86 m$^3$/h= Q | Pump Thickner | 19 |
| 14187.65 | 1 | 352 m$^3$/h= Q | Pump Thickner | 20 |
| 2264498 | 1 | 529 m$^3$/h =Q | Pump | 21 |
| 263848.4 | 1 | 705.75 m$^3$/h= Q | Pump | 22 |
| 2280058.84 | | Total | | |

## Operation Costs

1. Personal costs calculate show, all person salary (engineer, technician. workers) is 975$.

2. Deprecation Costs

   After passing the time, money will have extra value some amount of money at the first of year will have more value than the end of year. Deprecation will be estimate by three methods (liner. decreasing, total years integrated( formula 3,4) ) total amount of these Deprecation without considering to the time is fix [9].

$$D_j = \frac{N-J+1}{SUM}(P- S_v) \tag{3}$$

$$SUM = \frac{(N+1)N}{2} \tag{4}$$

   Which n , is project life and Sum is summation and D deprecation in year .In the other hand for calculating incomes according tax , deprecation will be reduction from income.

   If extra value is considering with the time so, deprecation is more, achieved taxes For project will be low, and will have more income, considering money extra value.

   Considering to above calculation third method year's digit summation will be suitable method for calculation of tax.

3. Electrician costs of Equipments
   According to the electrician prices for one Kwh 0.089 $ , and for year 188.58 $ for one shift per day.

4. Maintenance costs
   Maintenance costs is 10 percent of total costs of investment cost which is equal 4040451.3931 $.

5. Unpredicted costs.
   This costs is 10 percent of total costs of energy and maintenance and personal which is 4205006.6 $ and total costs of operation costs for one year is 4625507.224 $.

## Internal Rate If Return Calculation

this method is one of the general methods which is used in fact equal of incomes ( yearly , scraped values ) and costs ( primary investments , yearly costs ) with one rate is possible ( but not for always ) , and it is internal rate return . IRR should have the good condition for choosing of the project as a economical project estimating this rate , will be carried out by two methods ( recent value or income ) , that this rate is achieved by equaling of incomes and costs . so with using of formula ( 5 ) I will be calculated :

$$-P + A(p/A, I\%, n) + Sr(P/F, I\%, n) = 0 \qquad (5)$$

NPV=0

p: primary investment
Sr : scrap value
A: annual income
N: life project.

Considering formula (5) with n= 13, IRR is 34 % and without Sr IRR= 26 %. Considering to formula (6)

$$F = p(1+i)^n \qquad (6)$$

f= price in future, p= price at present

According to formula (6) price in 2004 has been obtained 227.8 $/ton but this price is price of one tone concentrate at mine, considering above. Real price will be 204 $/ton will be obtained which is real price of garnet in world market.

## ARGUMENT

Considering to this issue that in Iran approximately all of abrasive materials are achieved from garnet so production and extraction of this material is important from economic point in this paper additional to studding about sales and export situation has been considered if it will be compatible to world market. or from other countries it will be better to import , according to formula (6 ) a lot of parameters like sales price , primary investments , benefit and income , are effective in calculating ( IRR) so choosing the proper rate will play imported role in the project and changing of any parameters will effect in ( IRR) . Deprecation method can effect to income and tax. If the method is linear and inflation rate 9 percent. According figure 6 it can be resulted that it hasn't affect in reduction of tax, and during 13 year it flow one stable rate .But according to figure 7 with increasing of deprecation with (year digit summation method) in taxes and increase income.
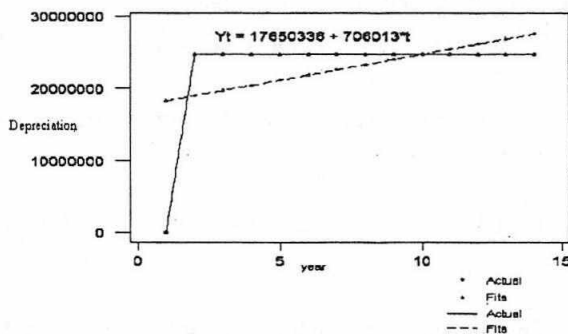


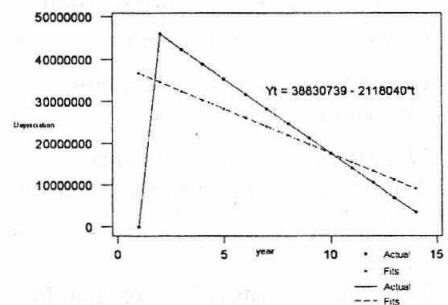Fig. 6: Time Analysis Depreciation with Linear Method

Fig. 7: Time Analysis Depreciation with Summation Year's Digits

Considering to inflation rate can effect to income positively and according to figure8, 9 with considering to inflation rate, income graph has more angles related to the time which inflation rate has not considered and the reason can effect to internal rate. considering to calculating of technical in this paper if bank value is 30 % and inflation rate is not considered IRR will be 23 % and considering to this , garnet price will be at the mine and market 209 , 183 $/ton , and with 9 percent inflation rate , internal rate of return will be 34 % and garnet will be 204 %/ton , 234 $/ton resulting to these items , investment back will have more angle related to not considering 9 percent , which shows investment backing will be fast ( figure 9 , 10 )
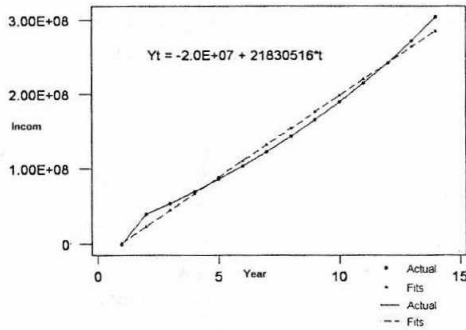
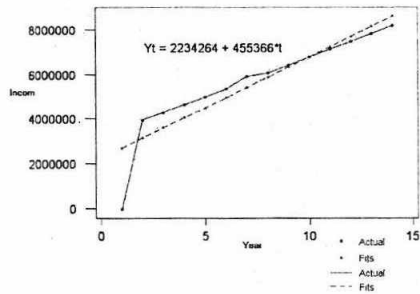Fig. 8: Time Analysis Income with Inflation Rate



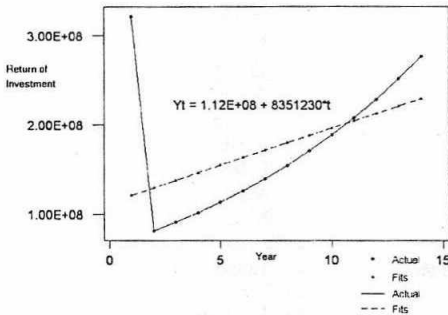Fig. 9: Time Analysis Income Without Inflation Rate



Fig. 10: Time Analysis Return of Investment with Inflation Rate
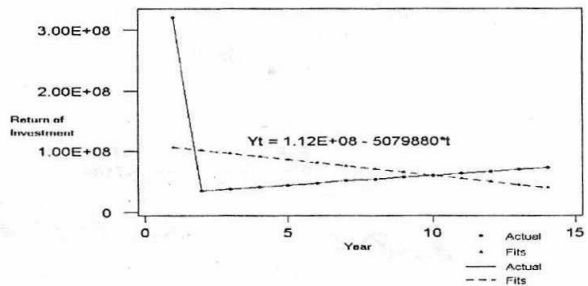


Fig. 11: Time Analysis Return of Investment Without Inflation Rate

Also, with considering scarp value, IRR and final price in market will be 26 %, 190 $/ton, that this shows scarp value can effect to change the price. Due to in this case internal rate will be lees than back value, and during in this 13 it will not feasible to invest with this amount of primary investment, so it should be more than this amount. additionally instead of garnet can effect to sale and production concentrate garnet in recent years with low production of garnet we use replacement abrasive with high price (220 $ /ton) but now with high production and decreasing .nternal rate of return we can use garnet for product abrasives material and lastly after design of flowsheet( fig 12), the necessary equipment selected and analyzed from technical and economic point of view . The result shown that internal return is 34%. There for the process is economic.

## CONCLUTION

1. Type of garnet at the Rafsanjan (Koh- E-Gabri ) according to studies in mineralogical and microscopy , ete result the garnet with 75 % its grade .

2. At present in Iran, a lot of compounded like Iron waste, copper waste , and silicon are used instead of garnet with high price .

3. Artificial abrasive like diamond is used in Iran instead of garnet to use the garnets reduce the environment pollution and dangers.

4. Considering to economic and technical studies also scrap value and inflation rate we can get this result that with scarp value , IRR will be 26 % which to this condition , project will not be feasibility , and without scrap value , IRR will be 34 % and with this condition flowsheet ( figure12 ) will be feasible , and we can sale the concentrate at mine and market 230 , 204 $/ton , and it shows that Koh0 E-Gabri can be competitive with the other garnet mine in the other

countries and with the best choosing of equipment ( table 7 ) abrasive paper factory can be start up . Which it will be have high effects to abrasive material in Iran also reduce imported garnet and ether abrasive materials.
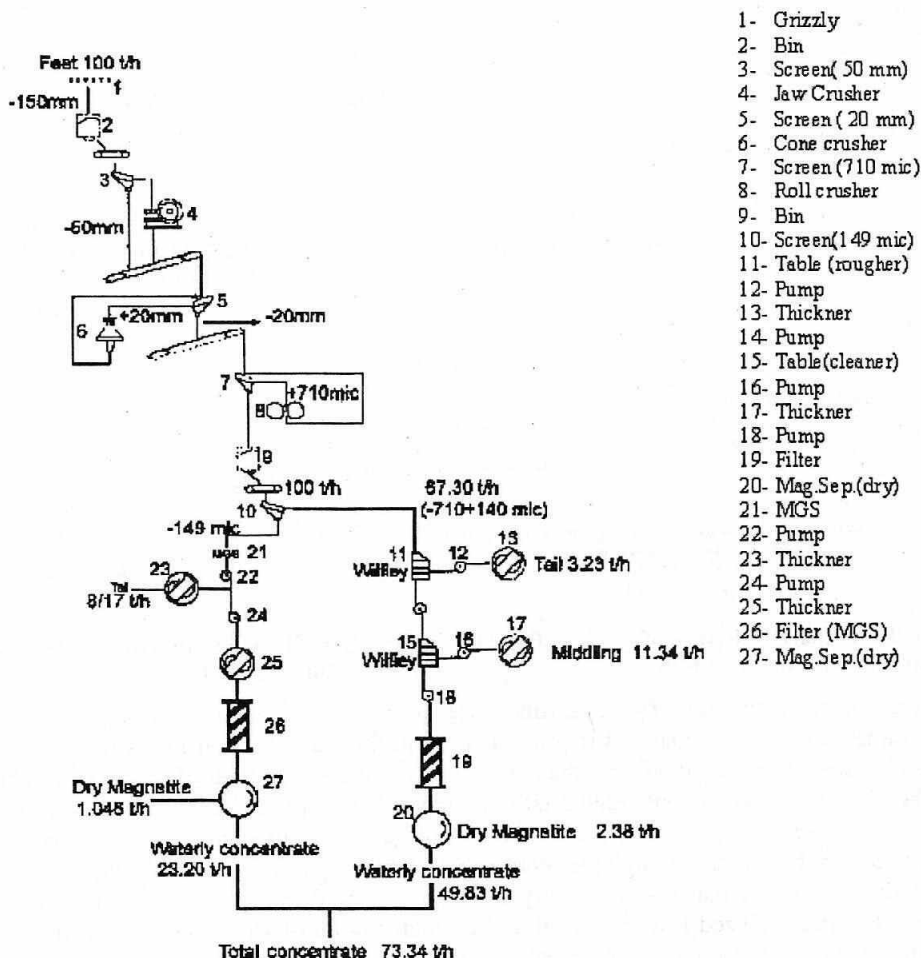


1- Grizzly
2- Bin
3- Screen( 50 mm)
4- Jaw Crusher
5- Screen ( 20 mm)
6- Cone crusher
7- Screen (710 mic)
8- Roll crusher
9- Bin
10- Screen(149 mic)
11- Table (rougher)
12- Pump
13- Thickner
14- Pump
15- Table(cleaner)
16- Pump
17- Thickner
18- Pump
19- Filter
20- Mag.Sep.(dry)
21- MGS
22- Pump
23- Thickner
24- Pump
25- Thickner
26- Filter (MGS)
27- Mag.Sep.(dry)

**Fig. 12: Final Flowsheet Based on Optimum Combination Techniques for Sample of Koh-E- Gabri Rafsanjan**

## ACKNOWLEDGMENTS

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