１. Purpose and Outline of the Study

１．Purpose and Outline of the Study

This study has been achieved for 39 months from October, 1999 to December, 2002 by Dowa Engineering Co. Ltd. and Mitsui Mineral Development Engineering Co. Ltd. based on the "Scope of work (S/w)" signed on June 4th, 1999, between Japan International Cooperation Agency (JICA) and Empresa Nacional de Mineria (ENAMI) for the study on "Environmentally-Friendly Operation of Mineral Processing Plant Using Biotechnology in the Republic of Chile" (hereinafter referred to as the Study).

The Republic of Chile (hereinafter referred to as Chile) is the world's largest producer of copper producing 4.6 million tons of the metal per year, but the other hand, there is increasing nationwide concern on environmental pollution in these days through rising consciousness and severer regulations than ever before. The main object of the Study is to introduce environmentally friendly operation using iron-oxidizing bacteria for waste water (solution) treatment, which has already been applied successfully in Japan, into mineral industry in Chile. For this purpose a model plant, with about 100m^3 per day of capacity to purify the waste solution, was installed at the site of the existing Ovalle leaching plant for demonstration test run as well as for technology transfer on this subject. A series of test results, are summarized in the Chapter 4 of this report.

For a large amount of investment to protect surrounding environment, it is inevitable to stabilize existing process and to improve operation results. In the present situation of Ovalle, ENAMI, some technical and environmental problems are found out to be solved, and also some unavoidable factors resulted from ENAMI's standpoint. To clarify these matters first, outline of ENAMI's position and its roles in the Chilean copper industry are generally described in the Chap. 2. Then, the results of Ovalle plant examination in the viewpoints of technical and environmental aspects are summarized in the Chap. 3 including economical consideration. This Report itself should be a warning and an important recommendation to be positioned in the environmental aspect.

The above-mentioned model plant was installed for test operation only and incapable of industrial scale operation. Thus, so-called "Full scale treatment plant", of which capacity meets the total volume of waste solution from the preceding leaching section, was designed for a future program. The total volume of the solution corresponds to the maximum capacity of the leaching section, 14,000 tons per month. Specifications and constructing costs of this full scale treatment plant are described in the Chap. 5.

In the Chap. 6, economical and financial analyses are broadly made to discuss the feasibility on the overall Ovalle plant including the waste solution treatment. As the main target of this Study was aimed at countermeasures against pollution, improvement of monthly profit is hardly expected directly from this investment. Accordingly in this Report, effects of environmental impact on outside community, meadow and farmland, were analyzed quantitatively for justification of the waste solution treatment plant.

Construction of the full scale plant is inevitably accompanied a large amount of investment.

Judging from the current situation of copper industry as well as ENAMI's itself, it would be unlikely to realize the investment at once.

In this Report, the full scale plant is strongly proposed for future program, when copper industry returned to another prosperity, on the other hand, more practicable countermeasure without causing pollution problems is studied as long as the current low level of operation is continued. This is described concretely in the Chap. 7.

Treatment of the waste solution with use of bacteria was technically proved through the Model plant operation. One purpose of this Study was application of this technology to other industrial sites in Chile. This is discussed in the Chap. 8, however, any mines or plants, which can introduce this technology as easily as Ovalle plant, are not found out inside Chile because copper precipitation process after leaching has been declining in recent years and even among the ENAMI plants, no promising future can not be seen to develop this operation. Thus, in the Chap. 8, general technical discussion is made on some industrial sites for any possibility of the application of this bio-technology. Now that this technology was satisfactorily transferred, it is expected to be developed by the hand of Chilean counterparts.

In the Chap. 9, discussions are summarized for conclusion of the Study. Through the realization of these proposals, Ovalle plant is expected to be a model plant inside Chile both in the technically and environmental standpoints.

２． Mining Situation in Chile

2. Mining Situation in Chile

2.1 Outline of Mining Industry

Chile has a leading role in the mining industry in the world, operating many metal mines especially in the Ⅱ and Ⅲ region, the northern part of the country as shown in Figure 2-1. Export of mining products (US$ 8.34billion in 2000) records as many as 47% of the total items. Especially export of Cu reached US$ 7.34billion in 2000 accounting for 41.5% of the total amount. Production of Cu has been increased year by year recording 4.6 million tons in 2000, 35% of world production, which now turns 13.2 million tons.

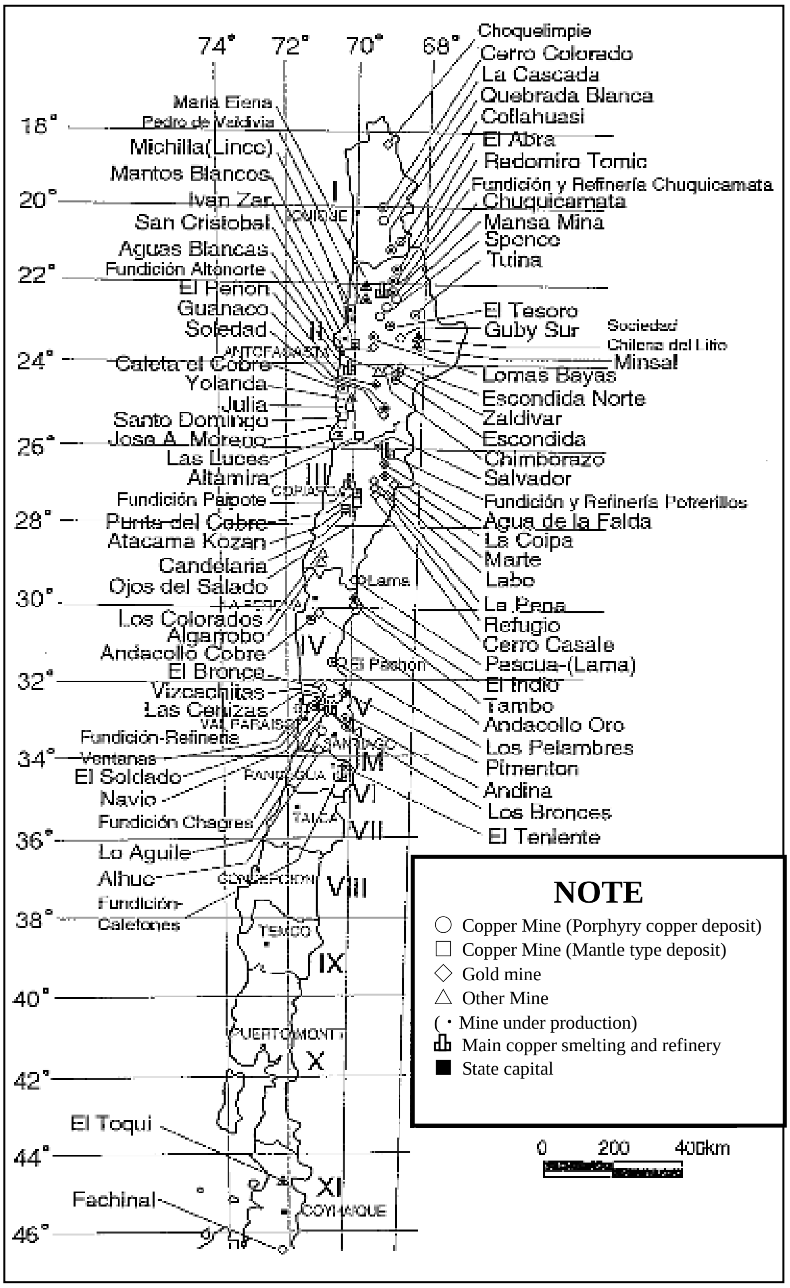


Figure 2-1 Major Mine Location in Chile

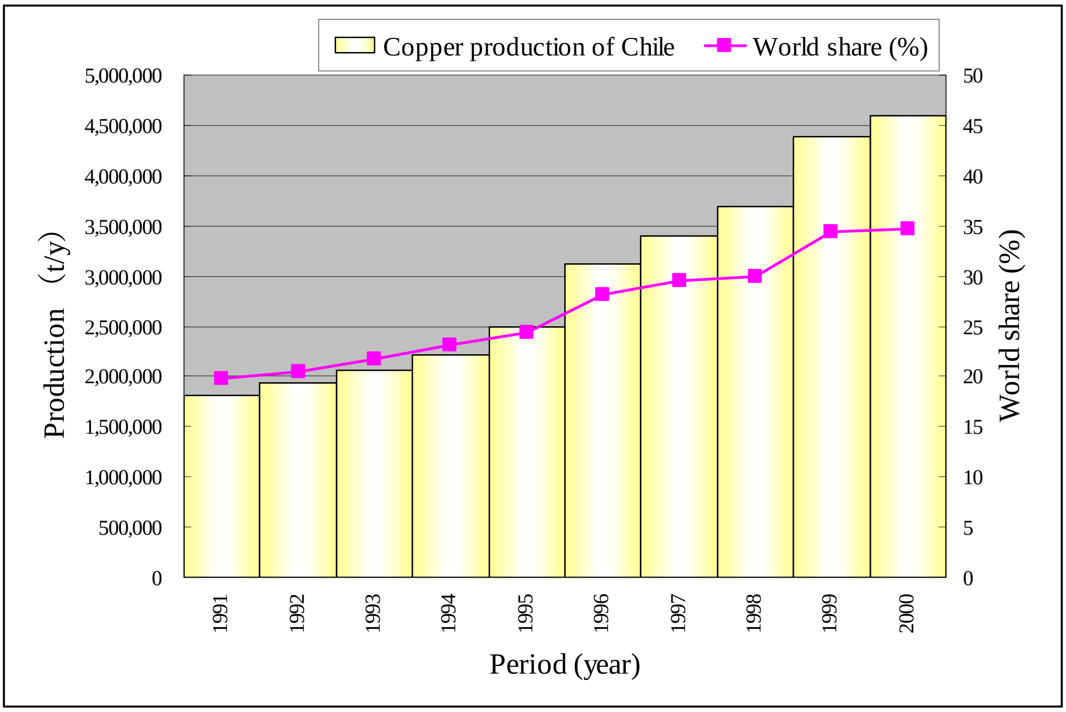


Figure 2-2 Recent Copper Production

2.2 Environmental Related Organization and Regulations in Chile

First environmental regulations goes back to 1916, "Regulations on neutralization and purification of industrial wastes". Since then, others have been arranged gradually under international movement, that is, "Sulfur dioxide from smelters", "Standards of floating dust" and "Regulations on water pollution" in 1991 as well as " Fundamental law on the natural environment" established in 1994.

1916	・Regulations on neutralization and purification of industrial wastes
1970	・Regulations on construction and control of waste tailing dams
1991	・Regulation on plant operation discharging sulfur dioxide, dust and arsenic
1992	・Regulations on neutralization and purification of industrial wastes (enforcement)
1994	・Fundamental law on the natural environment
1995	・Regulations on national and regional environmental advisory committee ・Regulations on promulgation of environmental and discharge standards ・Regulations for procedure of pollution control program
1997	・Regulations for environmental assessment
1998	・Discharge standards of pollutants accompanied with industrial waste water ・Standards of arsenic discharged into atmosphere
2000	・Standards of polluting elements contained in liquid wastes discharged into the sea or surface water

Other regulations than listed above, “Discharge standards into underground water”, “Discharge standards into the sea”, “Environmental standards for protection of surface water” and “Law on mine closing measures” are now being prepared for establishment.

An organization, which plays the important part in the environmental control of Chile, is CONAMA. When any environmental project is newly started, it is inevitable to submit a study report (or declaration) on its impacts to COREMAS (local environmental committee, subordinate to CONAMA) for final approval.

As for this Ovalle project, the declaration was already submitted to COREMAS and approved.

The organization of CONAMA and related institutions is illustrated in the following diagram.

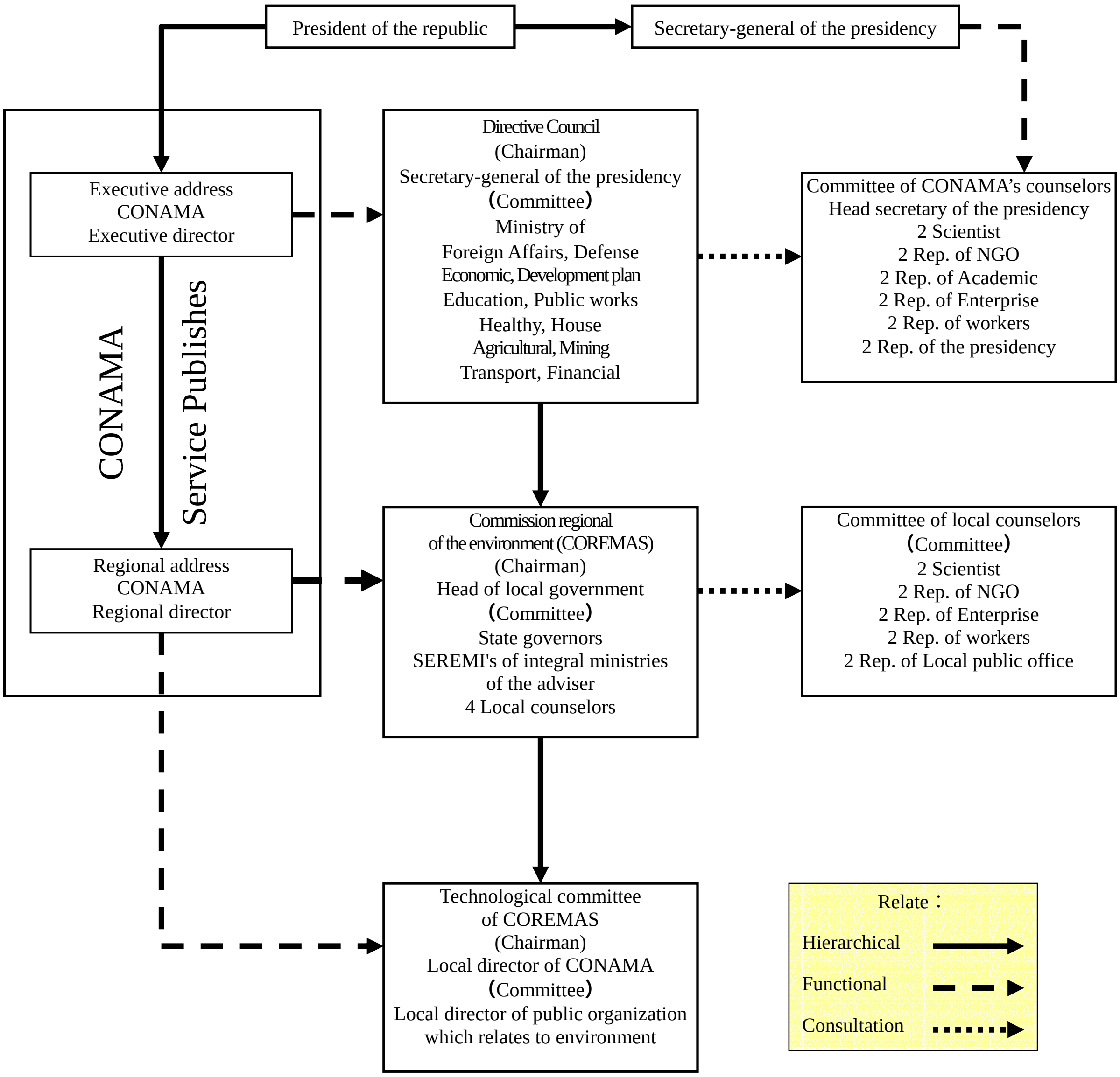


Figure 2-3 Organization Chart of CONAMA and Related Institutions

2.3 Outline of ENAMI

The National Mining Company, ENAMI (Empresa Nacional de Minería), was created in 1960 from the merger of the Fund for the Promotion and Funding of Mining (Caja de Credito y Fomento Minero) and its subsidiary, the National Smelting Company (Empresa Nacional de Fundiciones). Compared with another national mining company, CODELCO (Corporacion Nacional de Cobre de Chile), which is a giant profit-making enterprise operating world famous copper mines like Chuquicamata, El Teniente and others, ENAMI devotes itself to promote the development of small and medium-scale mining. Thus, without operating its own mines, ENAMI provides small or medium scale miners with partially subsidized services at purchase of ores to boost productivity, especially when copper price is unfavorable to the industry. Finally, ENAMI achieves its roll by processing these crude or intermediate materials through its plants and smelters to widely marketable products, like electrolytic copper, gold, silver and the like. In other words, ENAMI acts processing as well as marketing service on behalf of small or medium miners to promote this important sector of the nation. Its concrete measures are summarized as follows.

① Support mine development by financing

Development of mines is usually accompanied with financial risks because market price of copper often fluctuates. ENAMI provides the miners with long or short term loans, guarantee against risks and other benefits to promote the development.

② Ore processing

ENAMI processes crude ores from small or medium scale miners at the following plants through flotation or leaching process up to copper concentrate or precipitate respectively. Treatment capacity of each plant is listed below. These intermediate products are delivered to ENAMI's smelters for further treatment.

Table 2-1 ENAMI's processing plants

Name	State	Capacity（t-crude ore / month）			Product
		Oxide ore	Sulphide ore	Total	
Taltal	II	12,000	15,000	27,000	Copper precipitate / Copper concentrate
Matta	III	―	110,000	110,000	Copper concentrate
Vallenar	III	12,000	20,000	32,000	Copper precipitate / Copper concentrate
El Salado	III	18,000	―	18,000	Copper precipitate
Ovalle	IV	14,000	11,000	25,000	Copper precipitate / Copper concentrate
Total		50,300	152,000	212,000	

③ Custom smelting

At Ventanas and Paipote smelter, ENAMI treats copper concentrates and precipitates delivered from the above processing plants and also from the third parties. Ventanas smelter has an assembly line from smelting to electric refining and produces electrolytic copper as well as electrolytic gold and silver. On the other hand, Paipote produces anode copper through smelting, which is refined at Ventanas. As ENAMI gives the third party favorable treatment, difficulty often remains to make sufficient profit under current situation of copper price. Decrease in operation costs is urgent.

Table 2-2 Actual Results of ENAMI Smelting and Refining Operation (2000)

	Ventanas	Paipote
Electrolytic copper	319,105 t	—
Blister copper	—	77,639 t
Electrolytic gold	5,937 kg	—
Electrolytic silver	105,401 kg	—
Sulphuric acid	328,542 t	245,707 t

④ Engineering and others

ENAMI develops research programs like operation improvement, unique technology, environmental countermeasures etc., by itself or jointly with other party. As recent achievements, introduction of Teniente Converter, increase in SO_2 recovery from discharged gas and study on SX-EW process replacing traditional copper precipitation method are mentioned.

Other than technological promotion, ENAMI supports small and medium scale miners for smooth transport and distribution of materials and products through its local offices in each region.

ENAMI's business and services in the mining industry are reviewed above. Compared to CODELCO again, CODELCO produces 1.6 million tons of copper annually, ENAMI's output production from its smelters is only about 320 thousand tons, one fifth of the former. But ENAMI's role inside Chilean copper industry is so great for small and medium scale miners that they can compete with larger mines technically and commercially assuring employment by themselves.

Figure 2-4 shows the organization chart of the Ministry of Mines, which controls mining related institutions in Chile. Further, Figure 2-5 is the organization inside ENAMI.

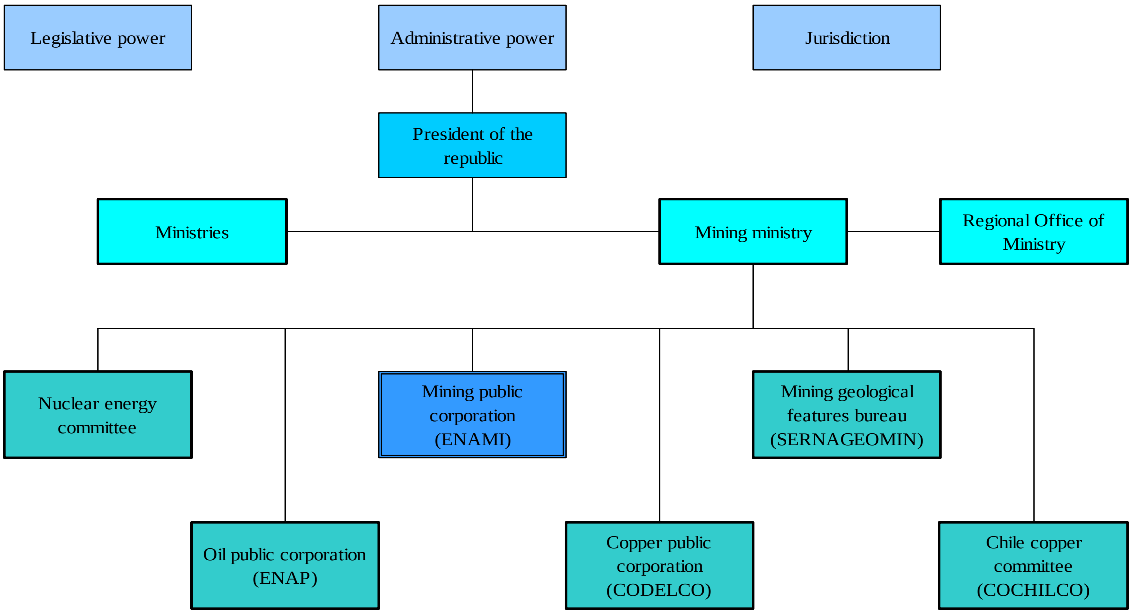


Figure 2-4 Organization Chart of the Ministry of Mines

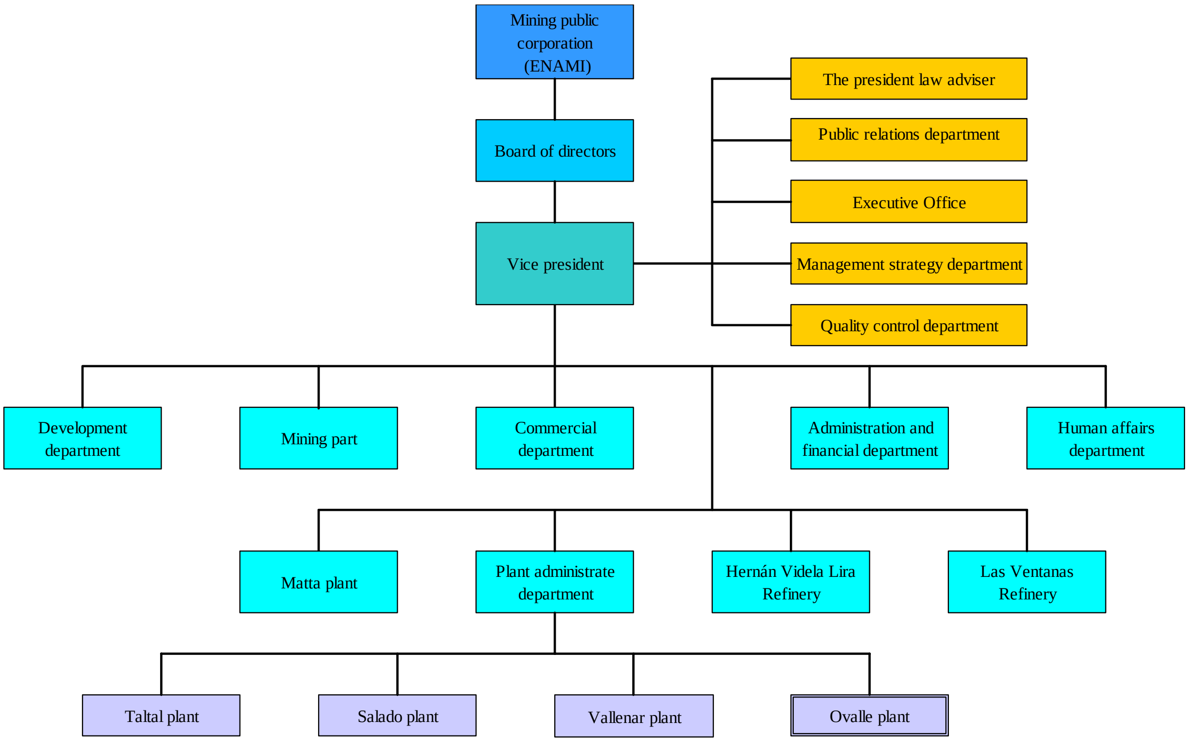


Figure 2-5 Organization Chart of ENAMI

Source：Annual report ENAMI, 2000

Compendio de la Minera Chilena, 2000

３． Examination of Ovalle Production Plants

3． Examination of Ovalle Production Plants

3.1 Outline of Ovalle Plants

3.1.1 Location

(1) Location and transport

This plant is situated at latitude 30.30' south and 71.06' west, 8km north from Ovalle city in Limari area, which is located at about 70km south from La Serena city(*1), capital of the Ⅳ region of the Republic of Chile. The plant is 444m above the sea level and faces Route No. 43, which connects La Serena and Ovalle. From La Serena it takes about one and half hours by car.

*1: 475km north from Santiago and 50 minutes by plane

(2) Landform

This area is called Cerro negro mountain area forming a coast mountain range. The plant is situated on a open slope of plateau facing a river, constructed after leveling the ground.

(3) Water basin

Underneath the plant flows the river Ingenio, a branch stream of the Limari, from NE to SW with about 1～8m^3/min. of water volume. The water springs at a riverbed about 6km upper stream from the plant, forming the Ingenio wet marsh zone and joins the river Limari at about 12km downstream from the plant.

Another water stream taken from Recoleta irrigation reservoir, called Talhuen, runs through the plant and further drinkable water is springing at eastern bank of the Ingenio, a little above the plant.

(4) Climate

During the dry season (Oct. through March), rainfall is scarce in this mountain zone. It is clear all day though foggy in the morning at the sea side. During the rainy season, on the contrary, it is cloudy and sometimes heavily rains. The maximum rainfall recorded 110mm/day in May, 1957 and in 1997 a flood was caused by heavy rain. Annual rainfall varies between 1～340mm/year but after 1993 it is less than 10mm/year except 1997.

3.1.2 History

- 1959 Compañia Minera de Panulcillo S.A. was founded. Started production of copper (Cu) precipitate through percolation leaching and Cu precipitation.
- 1999 Started as present Ovalle plant under direct control of ENAMI.

3.1.3 Production

(1) Situation of plant operation

Oxide and sulfide Cu ores are being processed. After 1998, when Cu price fell below 80￠/lb, operation has been inactive due to decrease in ore supply and consequently lower utilization of installed plant capacity.

Table 3-1 shows the outline of plant operation.

Table 3-1 Production Situation of Ovalle Plant, ENAMI

	Oxide copper ore	Sulfide copper ore
1.Processing minerals	Chrysocolla: $CuSiO_3 \cdot nH_2O$, Malachite: $CuCO_3 \cdot Cu(OH)_2$, etc.	Chalcopyrite: $CuFeS_2$, Bornite: Cu_5FeS_4, Covelline/Covellite: CuS, Chalcocite: Cu_2S, etc.
2.Treatment process	Precipitation process (Cementation process): Crushing+Agglomeration+Leaching+Precipitation ⇒ Product: Copper precipitate (Cement copper) with recovery of only Cu.	Flotation process: Crushing+ Grinding+Flotatio ⇒ Product: Copper concentrate with recovery of Cu, Au, Ag, Mo, etc.
3.Capacity	168,000t/year	84,000t/year[until summer, 2002]-132,000t/year[after summer, 2002]
4.Purchase of crude ore	Purchase from neighboring many middle, small and micro scale mines with incentives, because ENAMI has not any own mines according to the law of establishment of ENAMI to subsidize the mines. : Ore transportation distances are 3 to 120km. (bulk: 20～50km)	
5.Quantity of treatment in 2000	Crude ore: 42,365t/year [Grade Cu 2.3%] : RCU (Rate of capacity utilization) 25.2%	Crude ore: 47,418t/year [Grade Cu 1.7%, Au 0.3g/t and Ag 3.5g/t] : RCU (same as in the left) 56.4%
6.Quantity of production in 2000	Copper precipitate (Cement copper) 894t/year [Grade Cu 82.9%], [Recovery Cu 77.3%], [Quantity of metal Cu 741t/year]	Copper concentrate 3,068t/year [Grade Cu 22.3%, Au 2.0g/t, Ag 88.3g/t], [Recovery Cu 84.3%, Au 42.1%, Ag ---%], [Quantity of metal Cu 684t/year, Au 6.3kg/year, Ag 270.9kg/year]
7.Disposal of products	Disposal to Ventanas copper smelter, ENAMI	Disposal to Ventanas copper smelter, ENAMI

Note: Ovalle plant treats a very slight quantity of gold ore too in addition to copper ore.

(2) Position of output production

Table 3-2 shows how Ovalle plant is ranked in Chilean Cu producing industry. In 2000, the plant produced 1,425 tons of Cu, which accounts for only 0.03% of total domestic production, that is, $4{,}614.1 \times 10^3$ ton/year. But it should be noticed that ENAMI does not always stick production rank but aims at the promotion of the small and medium size miners.

Table 3-2　Position of Ovalle Plant in Chilean Cu Production(*2)　(in 2000)

	Quantity of copper production(*2)			Number of mines (and concentrators)
	Cu	Share		
	$\times 10^3$t/year	%		
1. (Ovalle plant, ENAMI)	(1.4)(*4)	(0.03)	(0.01)	(1)
2. Governmental: ENAMI	11.4	0.3	0.1	4
3. Governmental: CODELCO	1,612.4	34.9	12.2	6
4. Private(*3)	2,990.3	64.8	22.6	27
Total of Chile: 2.+3.+4.	4,614.1	100.0	34.9	36
Total of the world	13,230.0		100.0	

*2 : Production based on processing plants not on smelters. In Chile, only 7.4 $\times 10^3$ ton/year of Cu out of ENAMI's production and other minor portion are derived from Cu precipitate. Others are from sulfide Cu concentrate or cathode Cu through oxide Cu processing.

*3 : Among the private mines, Escondida mine holds the first place treating 175 $\times 10^3$ ton/day of sulfide crude ores (Cu 2.1%) and 70 $\times 10^3$ ton/day of oxide (Cu 0.68%) and produces 916.6 $\times 10^3$ ton/year of Cu metal (Cu concentrate : 2,021.5 $\times 10^3$ ton/year, Cu grade 38.4%, from sulfide ores as well as cathode Cu : 140.2 $\times 10^3$ ton/year, Cu grade 99.99% from oxide ores). This production accounts for 19.9% of total Chile and as many as 6.9% of world production.

*4 : Production of individual ENAMI plant is listed in Table 3-3.

3.1.4 Environment

Along the upper stream of the river Ingenio from Ovalle plant, no natural contamination is observed. On the contrary, the downstream from the plant is extensively contaminated by yellow green color of ferrous sulfate, $FeSO_4$, and red brown sediment of ferric hydro-oxide, Fe $(OH)_3$. Supposedly, these are caused by ferrous ions penetrated into the soil from the evaporation ponds(*5), which accumulate untreated waste solution from the leaching process.

*5: Formerly, the bank of the pond once collapsed when hit by earthquake.

This river water is partly used for irrigation but its iron content is above the standards for the use. Accordingly, Ovalle plant paid the agricultural bureau US$ 4,500 of fine in the past.

The new effluent standards applied to Ovalle plant were notified in the official gazette of March, 2001 with five year's grace period. Thus, the plant is strongly requested by CONAMA (National environmental committee) to take necessary measures by then.

On the other hand, flotation tailings from sulfide ore processing are piled up into the stock dam, of which overflow water is all circulated for reuse. No pollution is seen from this section.

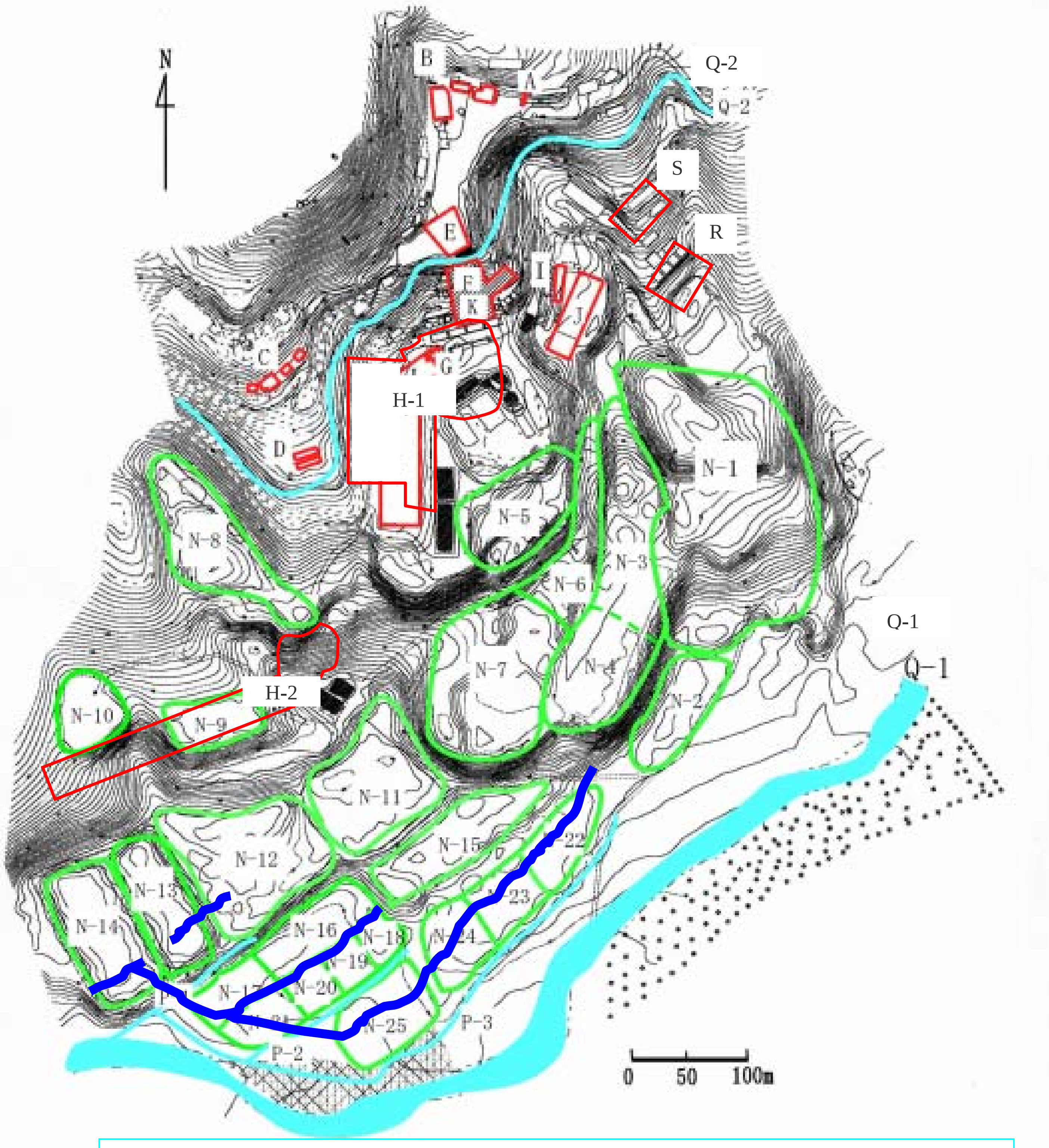
3.1.5 Location of Ovalle plant and related facilities

Fig. 3-1 illustrates correlated location of the plant and related facilities as well as surrounding water streams.

Table 3-3 Result of Operation of ENAMI Mineral Processing Plants in 2000 Source: MEMORIA ANUAL 2000, ENAMI

Item		Taltal	El Salado	Vallenar	Ovalle *9	Subtotal	M. A. Matta
1. Installed Capacity: by calculation							
1) Oxide copper ore (crude ore)	dry t/year	144,000	148,000	144,000	168,000	604,000	
2) Sulfide copper ore (crude ore)	dry t/year	180,000		240,000	84,000	504,000	1,320,000
1)＋2) amount of Installed Capacity	dry t/year	324,000	148,000	384,000	252,000	1,108,000	1,320,000
2. Reception: supply from mines							
1) Oxide copper ore (crude ore)	dry t/year	55,754	116,710	32,424	61,530	266,418	Closed by ore shortage
2) Sulfide copper ore (crude ore)	dry t/year	121,009		11,721	47,570	180,300	
3. Mineral Processing							
1) Oxide copper ore (crude ore) *1, *2	dry t/year	71,155	116,710	35,397	53,173	276,435	
: Rate of capacity utilization	%	49	79	25	32	61 *8	
2) Sulfide copper ore (crude ore) *1, *3	dry t/year	114,709		9,895	47,418	172,022	
: Rate of capacity utilization	%	64		4	56	35	
1) + 2) mineral processing ore tonnage	dry t/year	185,864	116,710	45,292	100,591	448,457	
3) Gravel (waste ore at primary leaching) *4	dry t/year	24,000	71,383	0	62,504	157,887	
4. Product							
1) Copper precipitate *5 〈from oxide Cu ore〉 tonnage	dry t/year	3,082	3,452	1,067	1,390	8,991	
Copper grade	%	79.66	84.03	81.51	81.95	81.91	
Copper tonnage	dry t/year	2,455	2,901	870	1,139	7,365	
Copper recovery	%	77.80	77.66	80.97	75.87	77.81	
2) Copper concentrate 〈from sulfide Cu ore〉 tonnage	dry t/year	10,168		1,054	3,072	14,294	
Copper grade	%	30.76		23.87	22.52	28.43	
Copper tonnage	dry t/year	3,128		252	684	4,064	
Copper recovery	%	93.20		100.37	84.40	91.96	
5. Cost: operation							
1) Purchase of oxide/sulfide copper ore (crude ore)	US$/t	2.42	5.33	7.07	4.10	4.00	
2) Crushing	US$/t	1.62	1.91	9.30	1.94	2.54	
3) Flotation *6	US$/t	8.92		6.16	10.73	9.38	
4) Leaching *7	US$/t	21.9	22.30	11.36	17.27	19.81	
5) Processing of oxide ore : 1) +2) +4)	US$/t	25.94	29.54	27.73	23.31	26.35	
	¢ /Cu-lb	34.1	53.9	51.2	49.4	44.9	
6) Processing of sulfide ore : 1) +2) +3)	US$/t	12.96		22.53	16.77	15.92	
	¢ /Cu-lb	21.6		40.1	52.7	30.6	

Note *1: Different from reception ore tonnage because of stock pile between reception and processing, *2: Crushing→Agglomeration→Leaching→Precipitation→Filtering,
*3: Crushing→Grinding→Flotation→Filtering, *4: It is assumed that the waste ore at primary leaching should be releached, but relation to other columns is not clear.,
*5: cement copper, *6: [Assumption] Grinding+Flotation+Filtering, *7: [Assumption] Agglomeration+Leaching+Precipitation+Filtering, *8: 46% in case of by calculation.
*9: Values of Ovalle plant calculated by ENAMI headquarter are different from them by Ovalle site.



	A~L, R, S	: Treatment plants and facilities related
	N	: Waste rock piling site, tailing ponds and waste water evaporation ponds
	P	: Canal for drainage of waste water infiltrated from evaporation ponds.
	Q-1	: River
	Q-2	: Irrigation canal

Note) Refer to the next page for details.

Figure 3-1　Location of Facilities of Ovalle Plant

<u>Details of legend for Figure 3-1</u>

Ａ：Main front gate of Ovalle plant
Ｂ：Materials warehouse
Ｃ：Main office
Ｄ：Plant cultivation house for mine pollution prevention vegetation
Ｅ：Acceptance ore stock yard: for oxide ores and sulfide ores
Ｆ：Crushing section for oxide ores and sulfide ores
Ｇ：Agglomeration section for oxide ores
Ｈ：Leaching section for oxide ores
　Ｈ-1　Primary leaching section (heap leaching) with leaching solution ponds
　Ｈ-2　Secondary leaching section (dump leaching) with leaching solution ponds
Ｉ：Precipitation (iron substitution and copper precipitation) section for oxide ores
Ｊ：Copper precipitation sun dryness section for oxide ores
Ｋ：Grinding and flotation section for sulfide ores
Ｌ：Copper concentrate sunlight drying section for sulfide ores
Ｎ：Waste ore stock pile and evaporation ponds for oxide ores, and tailing ponds for sulfide ores
　Ｎ-1　Sulfide copper ores: tailing pond 1 for old operation
　Ｎ-2　Sulfide gold ores: tailing pond 1 for old operation
　Ｎ-3　Sulfide copper ores: tailing pond 2 for present operation
　Ｎ-4　Sulfide gold ores: tailing pond 2 for old operation
　Ｎ-5　Oxide copper ores: percolation leaching waste ore for old operation
　Ｎ-6　Oxide copper ores: agitation leaching waste solution evaporation pond for old operation
　Ｎ-7　Oxide copper ores: leaching waste ore 1 for old operation
　Ｎ-8　Oxide copper ores: leaching waste ore 2 for old operation
　Ｎ-9　Oxide copper ores: leaching waste ore 3 for present operation
　Ｎ-10 Oxide copper ores: leaching waste ore 4 for present operation
　Ｎ-11 Oxide copper ores: leaching waste solution evaporation pond 1 } Not operation after the model plant was
　Ｎ-12 Oxide copper ores: leaching waste solution evaporation pond 2 } started to operate in Sep., 2001.
　Ｎ-13 Oxide copper ores: leaching waste solution evaporation pond 3 with HDPE seat lining (plan)
　Ｎ-14 Oxide copper ores: leaching waste solution evaporation pond 4 with HDPE seat lining (plan)
　Ｎ-15 Oxide copper ores: leaching waste solution evaporation pond 5 for outflow waste solution for old operation
　　　: There has been a collapse of the river side bank because of earthquake.
　Ｎ-16　　〃　　6 for outflow waste solution for old operation
　Ｎ-17　　〃　　7 for outflow waste solution for old operation
　Ｎ-18　　〃　　8 for outflow waste solution for old operation
　Ｎ-19　　〃　　9 for outflow waste solution for old operation
　Ｎ-20　　〃　　10 for outflow waste solution for old operation
　Ｎ-21　　〃　　11 for outflow waste solution for old operation
　Ｎ-22 Sulfide gold ores: tailing pond 3 for old operation
　Ｎ-23 Sulfide gold ores: tailing pond 4 for old operation
　Ｎ-24 Sulfide gold ores: tailing pond 5 for old operation
　Ｎ-25 Oxide copper ores: leaching waste solution evaporation pond 12 for outflow waste solution for old operation
Ｐ：Discharge canals for waste solution outflowed from evaporation ponds
　Ｐ-1　Discharge canal 1 for waste solution outflowed from evaporation pond
　Ｐ-2　Discharge canal 2 for waste solution outflowed from evaporation pond
　Ｐ-3　Discharge canal 3 for waste solution outflowed from evaporation pond
Ｑ：River and irrigation canal
　Ｑ-1　Ingenio river
　Ｑ-2　Talhuen irrigation canal for water supply
Ｒ：Model plant to treat waste solution from the leaching section
Ｓ：Test pilot plant to produce copper sulfate from pregnant leaching solution

3.2 Examination of Plant Operation

For stabilization of management performance and also for new investment of environmental countermeasures and others, it is inevitable to improve productivity and profits. In this section, profit increase and cost reduction at Ovalle production plants are generally discussed.

3.2.1 Comparison of various processing methods for Cu ores.

At Ovalle, oxide copper ores are processed through leaching-precipitation method to produce Cu precipitate, while sulfide ores are by flotation to produce Cu concentrate.

For general information, usual processing methods for two types(*1) of Cu ores are summarized in Table 3-4, considering the key factors like component minerals, production flow, possibility of by-product recovery, operating costs, operation scale and others.

*1: Oxide copper ores (leaching-precipitation or solvent extraction/electro-winning method) Sulfide ores (flotation-smelting-electrolytic refining)

3.2.2 Oxide ores

(1) Process at Ovalle

Oxide ores are processed by usual precipitation method, that is, crushing → agglomeration → leaching → precipitation (exchanging for iron scrap), to produce Cu precipitate.

Outline of flow diagram and material balance are shown in Figure 3-2.

(2) Operation results

After 1998, when market price of copper fell below 80 ¢ /lb, production has been inactive due to lower level of ore supply from outside. The actual operation results since 1994 are shown in Table 3-5.

(3) Discussion on profit increase

Total profit treating oxide copper ores is expressed as a functional formula as below.

$$\text{Profit} = \sum[\{\text{Cap.}\times A/100\times B/100\times(100-C)/100\times D/100\times E/100\}(100-F)/100\times G]$$

: Sum of each lot

Here, Cap. : Installed treatment capacity (ton/month or ton/year)

A : Rate of cap. utilization (%) B : Soluble Cu (%) in crude ore

C : Rate of handling losses (%) D : Recovery rate of Cu (%) in leaching step

E : Rate of Cu precipitation (reduction) (%)

F : Rate of waste time (%) G : Income received from ENAMI (US$/ton)

Table 3-5 Summary of Correlation between Capacity Use and Copper Price

Period		Cu metal price(*2) ¢ /lb			RCU (Rate of capacity utilization)(*3) %				
		Price	Range	Ave.	< 50	50～80	80～100	100 <	Ave.
94.01～ 97.11	Total 47 months	High	82～ 140	111.9	10 months [21 %]	18 months [38 %]	18 months [38 %]	1 month [2 %]	70.6 [100 %]
97.12～ 00.12	Total 37 months	Low	63～ 89	76.3	27 months [73 %]	9 months [24 %]	1 month [3 %]	0 month [0 %]	40.2 [100 %]

Note *2: LME Grade A Settlement

*3: Percentages in [ ] are shown to be proportion of number of months during the period.

(4) Cost Saving

Saving of manpower, energy and materials are studied.

(5) Processing methods for oxide Cu ores

Comparison of direct cost(*4) is made as below. Operation cost by precipitation method is much higher than SX-EW and disadvantageous. However, in case of medium scale operation like Ovalle plant, Cu precipitation method is still advantageous because of severe depreciation cost for SX-EW method, which accompanies a large amount of investment.

*4 : Comparison of total direct cost (standard)

Oxide Copper	Cementation	: Underground mining	70～90 ¢ /lb
	SX-EW	: Surface mining	30～50 ¢ /lb
Sulphide Copper	Smelting	: Underground mining	40～60 ¢ /lb
		: Surface mining	50～70 ¢ /lb

However, if supply of oxide ores is secured. SX-EW method should be discussed in future. And in case that copper sulfate ($CuSO_4 \cdot 5H_2O$) is produced, market research and feasibility study are indispensable.

(6) Summary

Table 3-6 summarizes the above-mentioned results or targets for oxide Cu ore processing.

・ Improvement 1 : Increase of income

① Increase in capacity use rate : Up from 25.2% [Y] in 2000 to 90.0%, an annual target Actual result was maximum 57.1% [X_2]

(Measure) Further increase of incentives for ore suppliers Mine management by ENAMI itself. Decrease in Cu cut-off grade of crude ores.
Constant operation of secondary leaching of primary waste rocks. Expectation of Cu price hike over 80～90 ¢ /lb etc.

② Increase of total Cu recovery : Up from 77.3% [Y] in 2000 to 81.5%[X_1], as a target. Actual result was maximum 81.5%[X_2].

(Measure) Decrease of Cu losses (Prevention of dust rising, wet treatment of fine particles etc.)

Increase of Cu recovery in leaching step (optimization of particle size, reuse of waste and treated solution, utilization of bacteria etc.)

Increase of Cu precipitation rate (by further control).

③ Grade of Cu precipitate : Up from 82.9% [Y] in 2000 to 83.0% as annual target[X_1]. Actual result was maximum 83.0% [X_2] so far.

(Measure) Further control needed.

・ Improvement 2 : Cost saving : Down from US$ 23.31/ton [Y] in 2000 to US$ 22.14/ton [X_1] as an annual target. The best result was US$22.14/ ton [$X_2$] so far.

(Measure) Cut down by 5% in every item.

With all these improvement, possible increase in operation profit was estimated in three cases, that is, annual target [X_1] (ore throughput = installed capacity (168,000t/year)× utilization rate 90% = 151,200t/year), the maximum of actual results [X_2] (throughput = 168,000t/year × utilization rate 57% =96,000t/year) and average result throughout 2000 [Y] (throughput = 42,365t/year). The increase of the profit should be the difference of each case , [X_1-Y] and [X_2-Y] respectively.

Regard to the gross profit, even if the increase in the rate of capacity use was achieved up to about 90% with realization of above mentioned improvements, Ovalle operation still stays in red.

As described in the Table, US$ 735,949/year of deficit (A-B in the Table) in the case of annual target [X_1] and also US$ 467,979/year in the case of the actual maximum [X_2] are respectively expected.

Numerical values in the parentheses show the results without technical improvements. This concludes that US$ 452,676/year of increase in gross profit in the case of annual target [X_1] and US$ 286,704/year in the case of the actual maximum [X_2] are expected by achieving the above improvements.

Summary of the Discussion on Gross Profit for Oxide Cu Processing (US$/year)

	Annual Target [X_1]	Actual Max. [X_2]	Year 2000 [Y]	Difference [X_1-Y]	Difference [X_2－Y]
Processing ore (t/year)	151,200	96,000	42,365		
Sales amount [A]	2,611,519 (2,335,846)	1,657,461 (1,483,077)	654,485	+1,957,034 (+1,681,361)	+1,002,976 (+828,592)
Production cost [B]	3,347,568 (3,524,471)	2,125,440 (2,237,760)	987,528	+2,360,040 (+2,536,943)	+1,137,912 (+1,250,232)
Profit [A－B]	-735,949 (-1,188,625)	-467,979 (-754,683)	-333,043	-402,906 (-855,582)	-134,936 (-421,640)
<Amount of improvement>	<+452,676>	<+286,704>			

Table 3-4　Comparison among Processing Methods for Copper Ores

		Oxide Copper Ore		Sulfide Copper Ore
1. Object Copper Ore : Major Minerals		Chrysocolla $CuSiO_3 \cdot nH_2O$、 Malachite $CuCO_3 \cdot Cu(OH)_2$, etc. Note: It could be possible to leach secondary sulfide minerals-namely, Chalcocite, Covelline/Covellite, etc., too, with bacteria.		Chalcopyrite $CuFeS_2$、 Chalcocite Cu_2S、 Covelline/Covellite CuS, etc.
2. Method of Production		Precipitation (Cementation)-Smelting process	SX-EW(Solvent extraction and Electro-winning) process	Mineral processing-Smelting process
3. Production Flow		Mining ↓ Run-of-mine ore (Crude ore) ↓ Crushing Agglomeration Leaching Precipitation ↓ Copper precipitate (Cement copper) ↓ Cu= about 75〜85% Smelting Conversion } Pyro-metallurgy Electro-refining ↓ Electrolytic Copper : Cathode Copper Cu≧ about 99.97%	Mining ↓ Run-of-mine ore (Crude ore) ↓ Crushing Agglomeration Leaching Solvent extraction Electro-winning } Hydro-metallurgy ↓ Electrolytic Copper : Cathode Copper Cu≧ about 99.97%	Mining ↓ Run-of-mine ore (Crude ore) ↓ Crushing Grinding Flotation } Mineral processing ↓ Copper concentrate ↓ Cu= about 25〜40% Smelting Conversion } Pyro-metallurgy Electro-refining ↓ Electrolytic Copper : Cathode Copper Cu≧ about 99.97%
4. Possibility of Au, Ag Recovery		×	×	○
5. Direct Cost (*1)				
5-1 Mining				
・Open pit (A)	¢/lb		○	9〜45, Ave. about 24
	$/t			0.5〜1.9, Ave. about 1
・Underground (B)	¢/lb	○		11〜97, Ave.about 38
	$/t			2〜30, Ave.about 12
5-2 Mineral Processing				
・Ore of (A)	¢/lb		○：Crush., Agglo., Leach.	5〜67, Ave. about 24
	$/t			1.5〜5.5, Ave. about 3
・Ore of (B)	¢/lb	○: Crushing, Agglomeration, Leaching, Precipitation		6〜27, Ave.about 14
	$/t			2〜15, Ave.about 5
5-3 Transportation	¢/lb	○: Cu precipitate		0.5〜8, Ave.about 3: Cu conc.
5-4 Smelting, etc.				
・Pyrometallurgy	¢/lb	○		8〜32, Ave.about 19
・Hydrometallurgy	¢/lb		○	
5-5 By-product	¢/lb			-1〜-130, Ave.about –22
(Au, Ag, Mo)				
Direct Cost Total (certain degree)				
・Ore of (A)	¢/lb		about 30〜50	about 40〜60
・Ore of (B)	¢/lb	about 70〜90		about 50〜70
6. Applied Scale		Small (to middle)	Big (*2)	Small to big

Note　*1: Total cost is composed of the direct cost, interest, depreciation, etc.., *2: In case of smaller scale, it goes to be impossible to conduct depreciation for solvent extraction and electro-winning facilities according to a smaller quantity of run-of-mine ore.

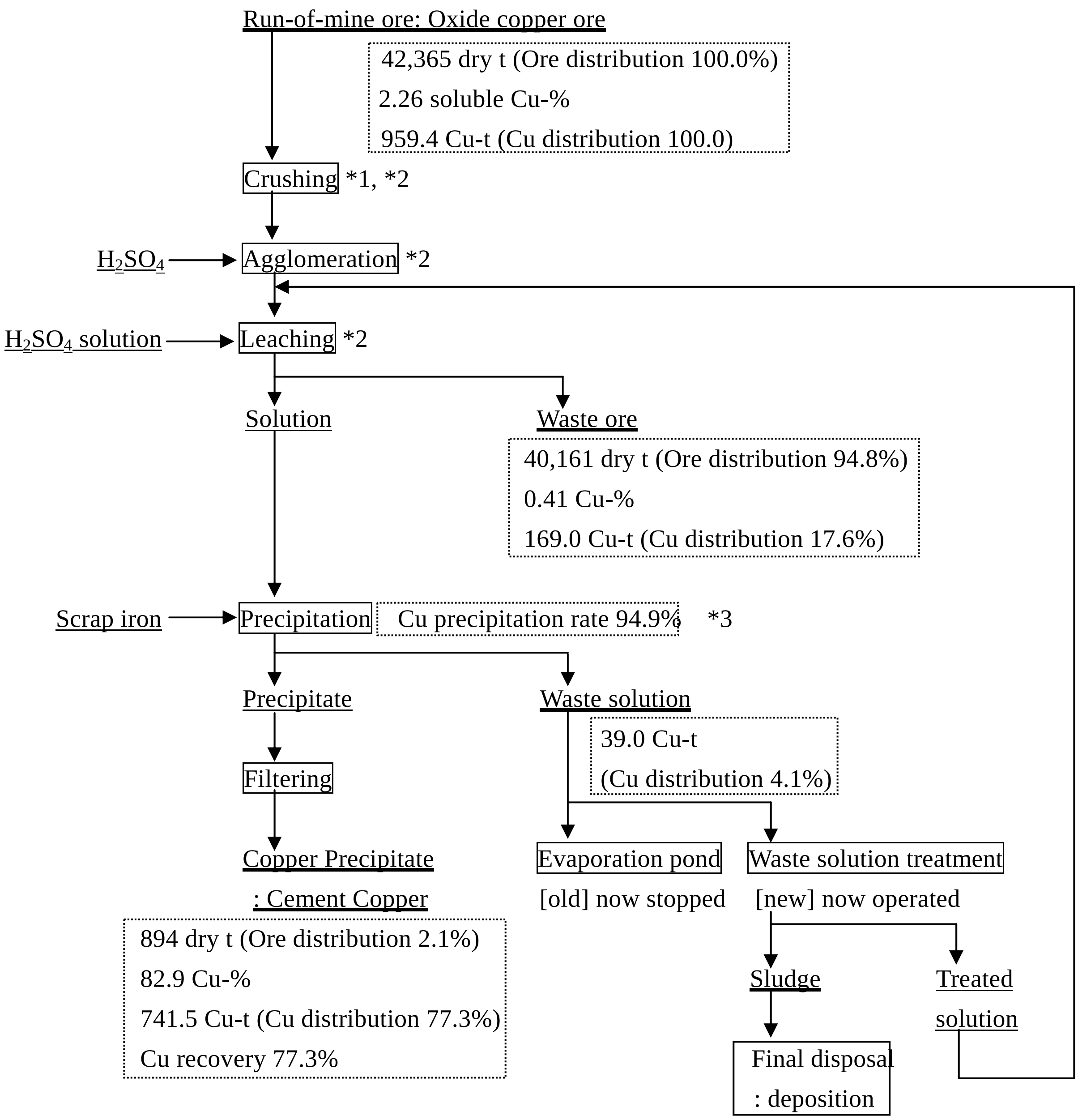


Figure 3-2 Block Diagram(outline) with Material Balance for Oxide Copper Ore in 2000
Ovalle Plant, ENAMI

Note *1: Every lot for reception ore should be weighed, sampled and analyzed at reception and crushing sections to decide commercial condition to buy ore.

*2: Loss in Crushing, Agglomeration and Leaching sections
424 dry t (Ore distribution 1.0%)
2.24 Cu-%
9.5 Cu-t (Cu distribution 1.0%)

*3: Loss in Precipitation section
0.5 Cu-t (Cu distribution 0.1%)

Table 3-6 Target of Processing for Oxide Copper Ore：Ovalle Plant, ENAMI

		For the year Target：X_1	Actual situat. Max.：X_2	In 2000 Result：Y	In 1994～2000 Results	Diff.：X_1-Y	Diff.：X_2-Y	Measures or expected outside circumference (◇)
1. Rate of capacity utilization: RCU	%	90.0	57.1	25.2	25.2～85.0: Ave.57.2	+64.8	+31.9	1) Incentive for custom ore by ENAMI
(1) Ore tonnage (grade of Cu)	t/year (Cu-%)	151,200 (same as right)	96,000 (same as right)	42,365 (2.3)	42,365～142,831: Ave.96,096 (1.9～2.3: Ave.2.1)	+108835 (±0)	+53,635 (±0)	2) Management of mine by ENAMI 3) Decrease of cut-off grade of custom ore
(2) Capacity	t/year	168,000	168,000	168,000	168,000	±0	±0	4) Steady secondary leaching for primary leaching waste 5) Copper metal price >80～90 ¢ /lb(◇)
2. Total Cu recovery rate （Formula）Total Cu recovery rate ＝{100－(Cu loss 1)}×(Cu leaching rate)/100 ×(Cu precipitation rate)/100 －Cu loss 2	%	81.5	(same as left)	77.3	56.8～77.3: Ave.72.1	+4.2	+4.2	
(1) Cu loss 1 distrib.: crush., agglom., leach.	%	0.5	(same as left)	1.0	0.9～1.1: Ave.1.0	-0.5	-0.5	1) Prevention of dust, 2) Wet treatment for fines
(2) Cu leaching rate: (Cu distrib. recovered by	%	86.3	(same as left)	82.2	60.3～82.2: Ave.76.7	+4.1	+4.1	1) Optimizing particle size, etc.
return of waste/treated solution to leaching section) [Ref.: Cu distrib. in waste solution]	%	(3.1) [1.0]	(same as left) (same as left)	(0.0) [4.1]	(0.0) [2.9～4.1: Ave.3.8]	(+3.1) [-3.1]	(+3.1) [-3.1]	2) Return of waste/treated solution to leaching section : utilization of bacteria, Fe^{3+}, etc.
(3) Cu precipitation rate	%	95.0	(same as left)	94.9	94.9～95.0: Ave.94.9	+0.1	+0.1	1) More management for stabilization
(4) Cu loss 2 distrib.：precipitation	%	0.05	(same as left)	0.05	0.05	±0	±0	1) ditto
3. Product: copper precipitate (cement copper)								
(1) Quantity of copper precipitate — 1) Quant.	t/year	Cal. 3,415	Cal. 2,168	894	894～2,907: Ave.1,865	+2,521	+1,274	
and grade of Cu of the one — 2) Grade	%	83.0	(same as left)	82.9	75.3～82.9: Ave.78.3	+0.1	+0.1	1) More management for stabilization
(2) Quantity of Cu — 1) Quant.	t/year	Cal. 2,834	Cal.1,799	741	741～2,261: Ave.1,448	+2,093	+1,058	
4. Income [A]：estimation	US$/year	2,611,519	1,657,461	654,485		+1,957,034	+1,002,976	
5. Production cost [B]	US$/year	3,347,568	2,125,440	987,528		+2,360,040	+1,137,912	
(1) Production unit cost	US$/crude ore t (¢ /prod.Cu-lb)	22.14 (Cal. 53.6)	(same as left) (Cal. 53.6)	23.31 (Cal. 60.5)		-1.17 (-4.8)	-1.17 (-4.8)	1) Reduction of cost of 5% for every item
6. Production gross profit [A－B]	US$/year	-735,949	-467,979	-333,043		-402,906	-134,936	
＜Improved money for operation＞	US$/year	<+452,676>	<+286,704>					

3.2.3 Sulfide Cu Ore Processing

(1) Processing method

From sulfide Cu ores, Cu concentrate is produced through crushing, grinding and flotation steps.

Outline of flow diagram and material balance sheet (actual results in 2000) are shown in Figure 3-3.

(2) Metallurgical results

After 1998, when Cu price is below 80 ¢/lb, production has stayed at lower level due to difficulty of crude ore supply.

Actual results of sulfide Cu ore processing after 1994 are shown in Table 3-7.

(3) Discussion on profit increase

Total income of plant operation is expressed as a functional formula as below.

$$\text{Income} = \sum [\{\text{Cap.} \times A/100 \times B/100 \times (100-C)/100 \times D/100\}(100-E)/100 \times F]$$

$\sum$: Sum of each lot

Here, Cap. : Installed capacity (t/month or t/year)

A : Rate of capacity utilization (%)

B : Cu grade (%) in crude ore

C : Rate of handling losses (%)

D : Cu recovery rate (%)

E : Rate of waste time (%)

F : Income received from ENAMI management

Table 3-7 The Relation between RCU at Ovalle vs. Cu Price

Period		Cu metal price(*5) ¢/lb			RCU (Rate of capacity utilization)(*6) %				
		Price	Range	Ave.	< 50	50～80	80～100	100 <	Ave.
94.01～97.11	Total 47 months	High	82～140	111.9	1 months [2 %]	15 months [32 %]	22 months [47 %]	9 months [19 %]	82.5 [100 %]
97.12～01.05	Total 42 months	Low	63～89	76.5	17 months [40 %]	20 months [48 %]	4 months [10 %]	1 month [2 %]	53.8 [100 %]

Note *5: LME Grade A Settlement、

*6: Percentages in [ ] are shown to be proportion of number of months during the period.

(4) Cost saving

① Saving of manpower, energy and materials are studied.

(5) Summary

Improvements of present operation are summarized in Table 3-8 as a target of the sulfide ore processing.

・Improvement 1 : Increase of income

① Increase in capacity utilization rate : Up to 90% as an annual target [X] from actual result 56.4% [Y] in 2000.

(Measure) Further increase of incentives for ore suppliers. Mine management by ENAMI itself. Decrease in cut-off grade of crude ores. Expectation of Cu price hike over 80～90 ¢ /lb etc.

② Increase of total Cu recovery : Up to 91.0% [X] as an annual target from 84.3%[Y] in 2000.

(Measure) Most suitable grinding circuit. Increase in flotation pulp density.

③ Increase of Cu concentrate grade : Up to 30.0% [X] as an annual target from 22.3%[Y] in 2000.

(Measure) Improvement of cleaning circuit. Employment of re-grinding. Study on column type machine in cleaning circuit.

・Improvement 2 : Cost saving

Cost down from US$ 16.77/ton [Y] of crude ore in 2000 to US$ 15.93/ton [X] as an annual target.

(Measure) Cost down by 5% on all items.

Based upon the improvement above described, annual gain in the gross profit is estimated as the difference between the annual target (Total throughput = installed capacity 84,000ton/year× utilization rate 90% = 75,600ton/year) and the actual result (47,418ton/year) in 2000, the recent year.

As the results, even if the rate of capacity utilization (operation rate) is increased up to 90% and also the above considerable improvements are realized, the operation inevitably stays in the red.

Thus, in the case of the annual target [X], US$ 188,940～253,305 of deficit is expected annually.

This estimate is summarized in the following Table. Inside the parenthesis show the results without any improvement of operation. In other words, <US$ 280,326～277,922> (in the Table below) of annual profit increase is expected with the improvement of the operation.

Summary of the Discussion on Gross Profit for Sulphide Cu Processing (US$/year)

	Annual Target [X]	Year 2000 [Y]	Difference [X-Y]
Processing ore (t/year)	75,600	47,418	+28,182
Sales amount [A]	1,015,368～951,003 (798,546～736,585)	493,362	+522,006～+457,641
Production cost [B]	1,204,308 (1,267,812)	795,200	+409,108
Profit [A－B]	-188,940～-253,305 (-469,266～-531,227)	-301,838	+112,898～+48,533
<Amount of improvement>	<+280,326～+277,922>		

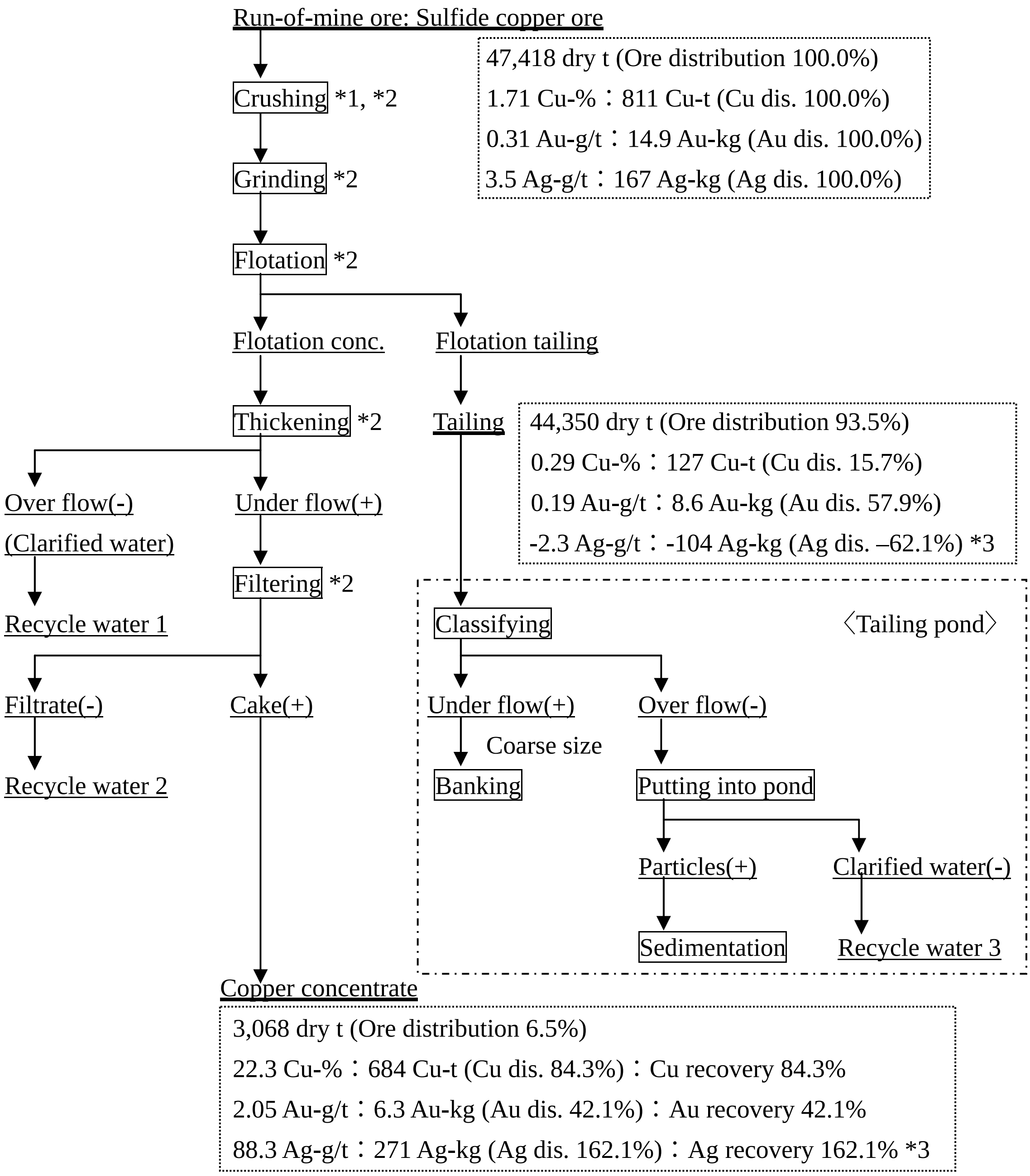


Figure 3-3 Block Diagram(outline) with Material Balance for Sulfide Copper Ore in 2000
Ovalle Plant, ENAMI

Note *1：Every lot for reception ore should be weighed, sampled and analyzed at reception and crushing sections to decide condition to buy ore.

*2：Loss of all sections should be none.

*3：Not clear.

Table 3-8　Target of Processing for Sulfide Copper Ore：Ovalle Plant, ENAMI

			For the year Target：X	In 2000 Result：Y	In 1994～2000 Results	Difference：X－Y	Measures or　expected outside circumference(◇)
1. Rate of capacity utilization: RCU		%	90.0	56.4	42.3～95.5: Ave.69.2	+33.6	1) Incentive for custom ore by ENAMI
(1) Ore tonnage (grade of Cu)		t/year (Cu-%)	75,600 (same as in the right)	47,418 (1.7)	35,572～80,196: Ave.58,128 (1.7～2.9: Ave.2.2)	+28,182 (±0)	2) Management of mine by ENAMI 3) Decrease of cut-off grade of custom ore
(2) Capacity		t/year	84,000	84,000	84,000	±0	4) Copper metal price >80～90 ¢ /lb (◇)
2. Recovery rate							
(1) Copper		%	91.0	84.3	84.3～93.5: Ave.89.9	+5.7	1) Adoption of optimum circuit of grinding 2) Reservation of flotation time by pulp density up
(2) Gold		%	---	42.1	42.1～179.8?: Ave.88.4	---	(ditto)
(3) Silver		%	---	162.1?	87.1～327.8?: Ave.135.4?	---	(ditto)
3. Product: copper concentrate							
(1) Quantity of copper concentrate	1) Quant.	t/year	Calculation 3,898	3,068	2,749～5,698: Ave.4,419	+788	1) Improvement of cleaning flow, and adoption regrinding at cleaning, 2) Adoption column flotation machine at cleaning
(2) Grade and quantity of Cu	1) Grade	%	30.0	22.3	22.0～29.1: Ave.26.4	+7.7	
	2) Quant.	t/year	Calculation 1,170	684	605～1,658: Ave.1,165	+473	
(3) Grade and quantity of Au	1) Grade	g/t	---	2.0	2.0～14.4: Ave.8.5	---	(ditto)
	2) Quant.	kg/year	---	6.3	6.3～81.9: Ave.37.5	---	
(4) Grade and quantity of Ag	1) Grade	g/t	---	88.3	88.3～198.3: Ave.140.2	---	(ditto)
	2) Quant.	kg/year	---	270.9	247.3～983.8: Ave.619.5	---	
4. Income [A]：estimation (*1)		US$/year	1,015,368～951,003	493,362		+522,006～+457,641	from ENAMI
5. Production cost [B]		US$/year	1,204,308	795,200		+409108	
(1) Production unit cost		US$/crude ore t	15.93	16.77		-0.84	1) Reduction of cost of 5% for every item.
		(¢ /prod.Cu-lb)	(Calculation 47.2)	(Calculation 52.7)		(-5.5)	
6. Production gross profit [A－B]		US$/year	-188,940～-253,305	-301,838		+112,898～+48,533	
＜Improved money for operation＞		US$/year	+280,326～+277,922				

Note　*1：Proportion (①＋②) of processing ore tonnage: Target [supposition] ① 60～30% in case of purchase with fixed price , ② 40～70% in case of purchase with special contract, Result of Feb. 2000: ① 50%, ② 50%

3.3 Examination on Environmental Situation

3.3.1 Purpose

The purpose of this examination is to survey the current environmental situation (water, soil, and air) around the Ovalle plant and to trace the roots of the pollution problems.

3.3.2 Water System and Quality around Ovalle

Water system in this area is illustrated in Figure 3-4 topographical map. One of the major rivers, the Ingenio flows southwest-ward along and joins the river Limari at the lower reaches 40 km from the Ovalle plant. There is spring water near the plant (eastern bank on the upper reaches of Ingenio) that is the only water for drinking in this area.

This is mountain area, 600 ～ 1000 m high around the plant. As the annual rainfall is as little as 80 ～ 100 mm, there is a little vegetation. Valleys and swamps are usually dry unless rain falls.

3.3.3 Water Quality・Monitoring Analysis

The following 9 sites were selected as monitoring (observation) points around the plant.

M-1: The Ingenio river (the upper stream of the plant)

M-2: Spring Water for Drinking.

M-3: Industrial water (Talhuen water)

M-4: Waste solution from precipitation process.

M-4A: Infiltrate drainage at downstream of evaporation pond

M-4B: Infiltrate drainage at upstream of evaporation pond

M-5: The Ingenio River (500 m down stream of the plant)

M-6: The Ingenio River (2 Km down stream of the plant)

M-7: The Ingenio River (5 Km down stream of the plant)

Water quality at the above points are checked and compiled as basic data once a month by Chilean side for environmental assessment.

In M-1, M-2 and M-3, the upper reaches of the plant, water quality is stable through the year. The content of T-Fe at M-1, M-2,M-3 is 0 ～ 0.3 mg/L that is under the standard for irrigation water. And higher content of Cl^- at M-2 will be affected by chlorination of drinking water.

As to the group of pollution roots (M-4, M-4A and M-4B), water quality of M-4 (waste solution from leaching process) is very instable. The content of T-Fe fluctuates from 9g/L to 39g/L that is caused by instable operation in the oxide ore treating process. The content of T-Fe is a key factor for operating new plant because Fe-ion shall keep the activity of iron oxidizing bacteria.

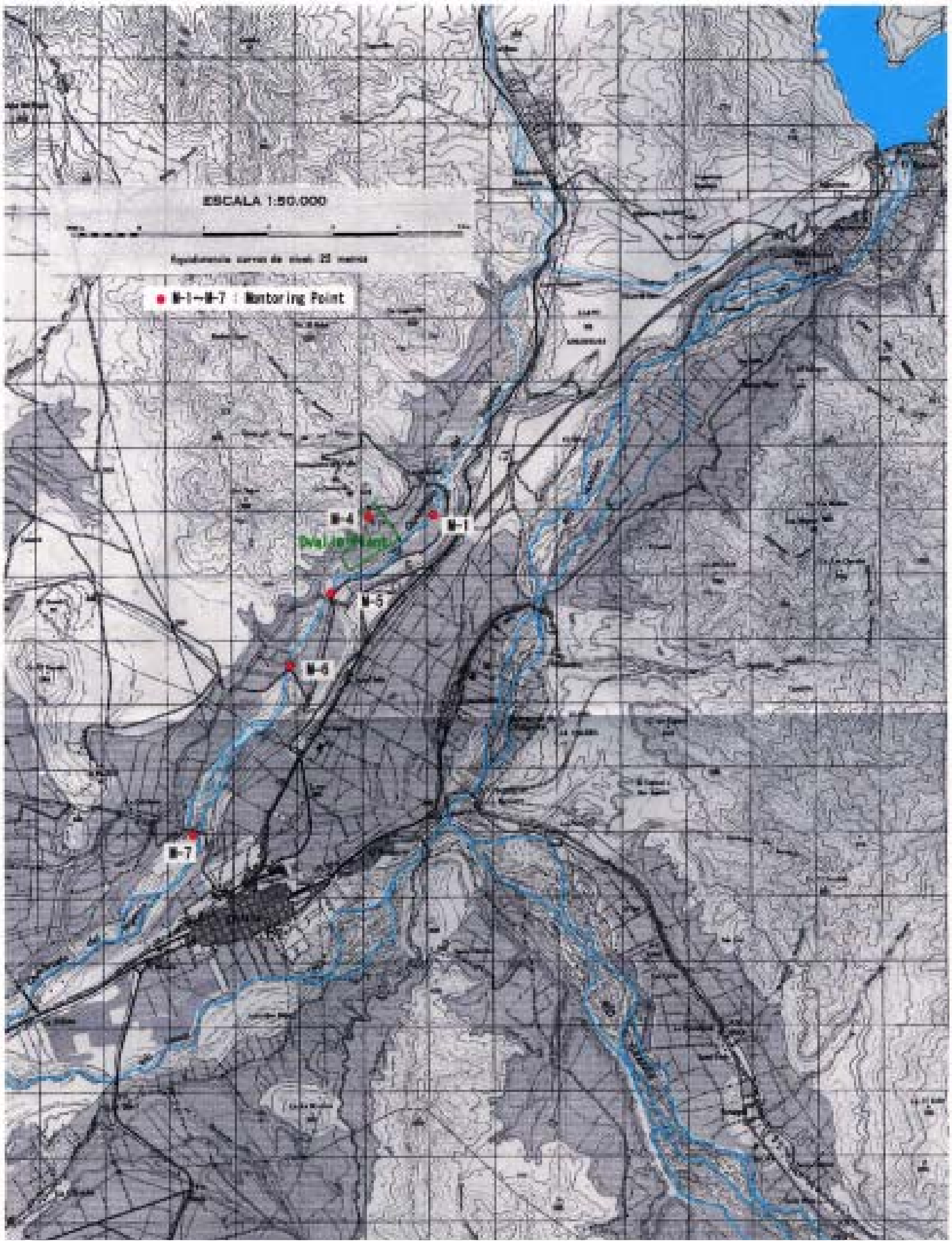


Figure 3-4 Topographic Map

M-4A seems to be penetrated from the evaporating ponds and diluted a little with surrounding water. M-4B is different from M-4A and M-4, seems to be penetrated mainly from the plant.

As to M-5, M-6, M-7, the Ingenio River flow increase in April until September, then the water of M-5, M-6 and M-7 are diluted much and the density of the contaminants decrease in these season. But at M-5, M-6, the each content of T-Fe, Cu, Al, Mn and SO_4^{2-} are very high through the year. Then finally, at M-7, the each content of T-Fe, Cu, Al is decreasing by the effect of natural purification.

3.3.4 Countermeasures against Water, Soil and Air Pollution

(1) Waste Water ／Irrigation Water Standard in Chile

Table 3-9 Standard for Industrial Waste Water・Waste Liquid /Irrigation Water (metal mining concerned)

Contaminant (Regulatory Substance)	Unit	Standard for discharge of industrial waste water into sewer	Standard for Waste Liquid					Standard for Irrigation Water
			No.1: Into river	No.2: Into the river considered to have a dilute-capacity	No.3: Into lake	No.4: Within a protected coastal sea area	No.5: Without a protected coastal sea area	
PH		5.5－9.0	6.0－8.5	6.0－8.5	6.0－8.5	6.0－9.0	5.5－9.0	5.5－9.0
Temperature	℃	35	35	40	30	30	-	-
Total suspended solid	mg/L	300	80	300	80	100	700	-
Sedimentary solid	ml/L 1h	20	-	-	5	5	50	-
Al	mg/L	10	5	10	1	1	10	5
As	mg/L	0.5	0.5	1	0.1	0.2	0.5	0.1
B	mg/L	4	0.75	3	-	-	-	0.75
Cd	mg/L	0.5	0.01	0.3	0.02	0.02	0.5	0.01
CN^-	mg/L	1	0.2	1	0.5	0.5	1	0.2
Cl^-	mg/L	-	400	2,000	-	-	-	200
Cu	mg/L	3	-	-	-	1	3	0.2
T-Cu	mg/L	-	1	3	0.1	-	-	-
T-Cr	mg/L	10	-	-	2.5	2.5	10	0.2
Cr^{6+}	mg/L	0.5	0.05	0.2	0.2	0.2	0.5	-
Sn	mg/L	-	-	-	0.5	0.5	1	-
F	mg/L	-	1.5	5	1	1.5	6	1
Fe	mg/L	-	5	10	2	10	-	5
Mn	mg/L	4	0.3	3	0.5	2	4	0.2
Hg	mg/L	0.02	0.001	0.01	0.005	0.005	0.02	0.001
Mo	mg/L	-	1	2.5	0.07	0.1	0.5	0.01
Ni	mg/L	4	0.2	3	0.5	2	4	0.2
Pb	mg/L	1	0.05	0.5	0.2	0.2	1	5
Se	mg/L	-	0.01	0.1	0.01	0.01	0.03	0.02
SO_4^{2-}	mg/L	1,000	1,000	2,000	1,000	-	-	250
S^{2-}	mg/L	5	1	10	1	1	5	-
Zn	mg/L	5	3	20	5	5	5	2

The new waste water standard of Chile was published on March 2001. "The standard for the river which is considered to have a dilute-capacity" shown in No.2 of above table or "Discharge standards into underground water" enactment schedule in 2003, should be applied to the waste solution from the Ovalle plant.

In this new regulation, these new standard will come into effect on existing plants such as Ovalle plant after 5 years. That means this new standard will act after 2006 in this law.

On the other hand, in the case of Irrigation Water Standard applied, the each content of T-Fe, Cu, Al, Mn and SO_4^{2-} in Ingenio river at M-5, M-6 and the content of Mn and SO_4^{2-} at M-7 are exceeding Irrigation Water Standard and it seems that Ingenio river (M-5, M-6, M-7) is not good for irrigation water.

(2) Countermeasures against Water Pollution

The total volume of M-4 penetrating into the Ingenio River is estimated in Table 3-10 below by the flux volume difference of T-Fe between M-1 and M-5.

Table 3-10 Calculated Flux Volume of penetrating drainage (M-4)

	T-Fe[mg/s] (M-5)-(M-1)	M-4	
		T-Fe[mg/L]	Q [L/s]
Dec	39,088	29,550	1.32
Jan. 2000	28,164	17,240	1.63
Feb	44,379	-	-
Mar	52,784	39,290	1.34
Apr	35,989	37,040	0.97
May	84,746	25,340	3.34
Jun	87,145	24,830	3.51
Jul	34,820	14,570	2.39
Aug	30,741	18,670	1.65
Sep	91,931	15,100	6.09
Oct	56,415	11,140	5.06
Nov	30,871	16,000	1.93
Dec	20,256	19,590	1.03
Jan. 2001	21,970	18,660	1.18
Feb	22,245	28,620	0.78
Mar	24,889	25,600	0.97
Apr	28,220	25,000	1.13
May	81,895	14,390	5.69
Jun	3,130	15,000	0.21
Jul	33,741	23,470	1.44
Aug	10,041	9,800	1.02
Sep	7,772	15,400	0.50
Oct	16,559	17,110	0.97
Nov	33,970	12,150	2.80
Dec	60,910	10,700	5.69
Jan. 2002	56,455	15,000	3.76
Feb	127,686	18,000	7.09

The total volume of M-4 penetrating into the Ingenio River is affected by the plant operation ratio and seasonal rainfall. As shown in Table 3-10, the penetrating volume of M-4 comes to 3 ～ 7 L/sec. But otherwise it comes around 1 L/sec or less.

Contaminants in M-4, T-Fe, Cu, Al, Mn, As, Zn, Cd, SO_4^{2-}, in M-4A, T-Fe, Cu, Al, Mn, Zn, Cd, SO_4^{2-} and in M-4B, Cu, Al, Mn, Zn, SO_4^{2-} are exceeding the Waste Water standard.

And it will become harder in the case of Irrigation Water standard applied. T-Fe, Cu, Al, Mn, As, Zn, Cd, SO_4^{2-} in M-5 and M-6, Mn, Zn, SO_4^{2-} in M-7 are exceeding that standard.

The route of waste water penetrating from plant into the Ingenio River should be complicated. But the waste water of M-4A and M-4B always flow under the dike of the evaporating ponds. It is sure that M-4A and M-4B flow into the Ingenio River.

Analytical result shows that M-4B might be the water coming together from inside of the plant and has less effect on the Ingenio River contamination. But M-4A will be the major pollution source of the Ingenio River contamination. It is penetrating from evaporating pond where M-4 water is fully stored.

The following countermeasures should be examined and applied at the Ovalle plant in order to prevent the water pollution until 2006 when the new regulation comes into effect.

① Lining HDPE(High Density Poly-Ethylene) sheet inside of the evaporating pond ;
To prevent the penetration from the evaporating pond, cover the impervious layer such as HDPE sheet inside of the pond.

② Reforming the dike of the evaporating pond ;
Reform the broken parts or rain wash of the dike and analyze the stability of the dike

③ Reforming the surroundings of the evaporating pond ;
Reform the leaching waste and cover the soil, then vegetate on them

④ Arrangement of the channel ;
Set up the open channels around the plant and the pond to shut down the flood of rainfall.

⑤ Study on the stability of the neutralized sediment ;
Examine the stability of the neutralized sediment by dissolution test and fluidity test in case of containing much water.

(3) Countermeasures against Soil Pollution

The ferric sediments containing some metals, leaching waste, tailing, and accumulated dusts etc in the Ingenio River possibly cause soil pollution around the Ovalle plant. Especially, a large amount of ferric sediments (hydrated iron) is accumulating widely in the river from the monitoring point M-5 (500 m down stream of the plant) to M-7 (5 Km down stream of the plant).

In the future, when the total volume of the waste water (M-4) from the leaching plant is properly treated and these countermeasures mentioned above is completed, soil pollution around the Ovalle plant would be prevented. And moreover, it will take much time that new fresh sediments coming from upper stream of Ingenio River will cover the old polluted sediments gradually and naturally.

If all polluted sediments in the Ingenio River would be removed, it must require a huge cost and much time. Otherwise, actual damages to living life of the residents around the Ovalle plant are not reported at the moment. It is quite reasonable to make use of these natural forces.

(4) Countermeasures against Air Pollution

The dusts from the crushing process, acid mist from spraying and the dusts from the residue or the neutralized sediments in the evaporating ponds are all likely to cause air pollution around the Ovalle plant.

There are some vineries around the Ovalle plant. It is required to prevent the scattering of these dusts as much as possible. The followings are recommended as the countermeasures.

① Spraying on the crushing, agglomeration and transportation process to prevent the scattering of dusts.

② Setting windbreak-net etc to prevent acid mist from spraying on leaching pad.

③ Reforming, soil-covering and vegetation should be applied on leaching wastes, tailings, the residue or the neutralized sediments in the evaporating ponds.

４． Technical transfer of Iron Oxidizing Bacteria Method

4. Technical Transfer of Iron Oxidizing Bacteria Method

4.1 Basic Laboratory Tests

4.1.1 Purpose

Basic laboratory tests were carried out to obtain fundamental data for installation of a model plant, treating waste solution from the precipitation step of Ovalle leaching plant and to transfer the related technology to the Chilean counterparts.

4.1.2 Test Items and Results

The major items are summarized as follows.

- Survey of iron-oxidizing bacteria
- Oxidation tests
- Confirmation of negative factors against bacteria activity
- Neutralization tests using local reagents
- Flocculation and settling tests
- Filtering tests

From these tests the following results were obtained.

- Actual waste solution from Ovalle can be oxidized with use of bacteria, taken inside Chile.
- Necessary data were obtained for the design of oxidation, neutralization and filtering step in the model plant.
- Andacollo strain should be employed as oxidizing bacteria when the model plant is started.

4.2 Installation and Outline of the Model Plant

4.2.1 Progress of Installation of the Model Plant

Based on the S/W, signed in June, 1999 between JICA and ENAMI, the Japanese side had been in charge of plant design, procurement of machinery and equipment, marine transportation and dispatch of supervising members for the installation, while the Chilean side carried out inland transportation, civil and building works and installation of equipment. The plant was completed in early September, 2001 as scheduled and then, demonstration test run was started under the collaboration of the both sides. Outline of the plant is described in the following section.

4.2.2 Outline of the Plant

(1) Process Flow

Flow diagram is shown below.

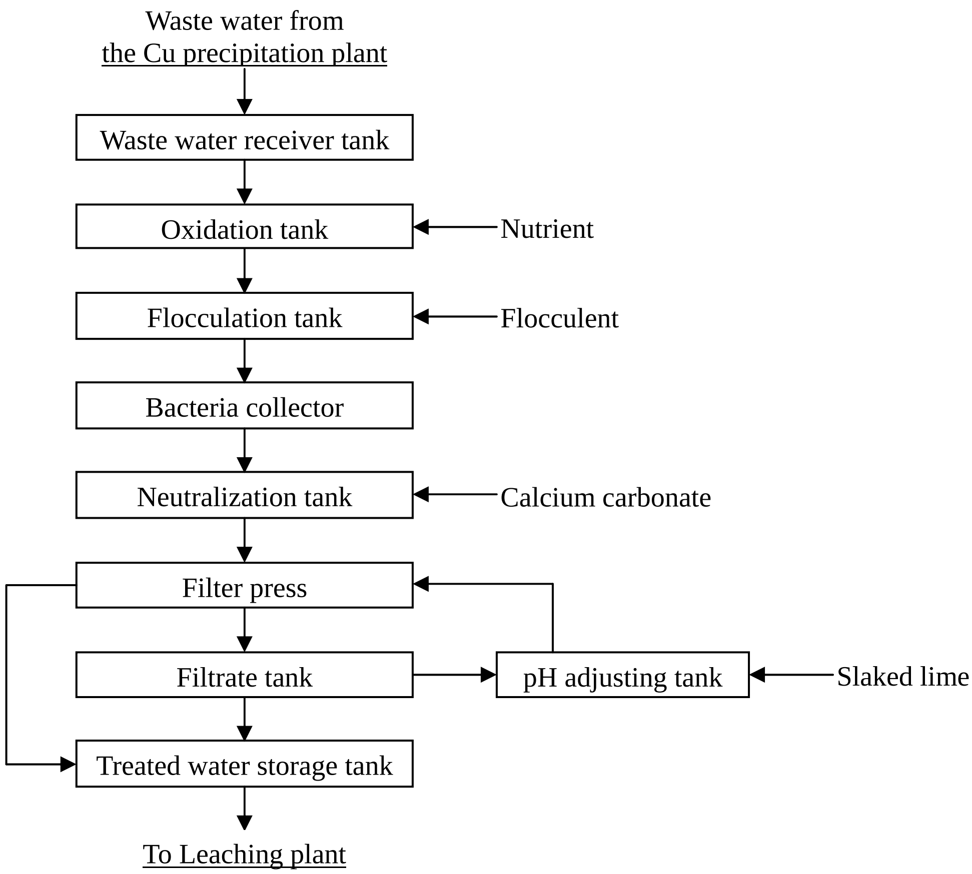


Figure 4-1 Process Flow of the Model Plant

(2) Bases of Design

Bases of design are described below.

1) Quality of waste solution from the leaching plant

Quality of waste solution that is fed to the model plant was fixed as follows by mutual agreement.

Table 4-1 Specification of Waste Solution to be Treated

(g/L)

pH	Fe^{2+}	T-Fe	Cu	Mn	Zn	Al
3.7	30	30	0.26	0.97	0.24	9.7

2) Capacity of the model plant

Treatment capacity of the model plant was set at $100m^3$/day by mutual agreement.

3) Oxidizing rate

The plant was designed with 1.0g/L/h of oxidizing rate for Fe^{2+}.

4.3 Results of Demonstration Tests

4.3.1 Purpose

The comprehensive purpose is to obtain necessary data for performing the feasibility study (F/S) on a large-scale waste solution treatment plant at Ovalle as well as for transferring the related technology to the counterparts.

4.3.2 Test Results

(1) Quality of Feed Solution

Quality of feed solution throughout the test period is shown in Table 4-2. Each component was a little lower than originally expected.

Table 4-2 Analytical Results of Feed Solution

element	pH	Fe^{2+} (g/L)	T-Fe (g/L)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	Al (mg/L)	Cd (mg/L)	Pb (mg/L)	As (mg/L)	Mg (mg/L)
Av.	**3.3**	**17.02**	**20.66**	**101**	**466**	**208**	**2770**	**1.56**	**0.75**	**17.1**	**3190**
Max.	2.6	32.93	40.60	253	837	484	4949	2.90	1.30	30.0	3807
Min.	3.8	7.90	8.29	28	251	106	1588	0.78	N.D.	7.0	2590

(2) Test Conditions

The final results were attained under the following conditions.

Table 4-3 Test Conditions

Item	Condition, Results
Treatment volume	・Possible to treat $100m^3$/day or more. ・The maximum volume is supposed to a $176m^3$/day
Volume of bacteria sludge	・Quarter volume of feed solution
Addition of nutrient	・2.5mg/L to the feed solution
Addition of high molecular flocculent	・5mg/L to the feed solution
Neutralization pH with calcium carbonate	・Neutralization pH＝3.5-4 ・Average consumption of calcium carbonate is about 17g/L.
Neutralization pH with slaked lime	・Neutralization pH=8-9 ・Average consumption of slaked lime is about 12g/L.

(3) Operational Results at the Model Plant

1) Reagent cost is estimated at around US$ 115/day when $100m^3$ of waste solution is treated per day.

2) Leaching tests carried by the Chilean counterparts showed that the treated solution (model plant effluent) could be reused at the leaching step without any harmful effects. It was also suggested the oxidized solution (after oxidation step) would promote leaching of Cu minerals if it is mixed suitably with the original leach solvent.

3) When $100m^3$ of the waste solution is treated a day at the model plant, about 12.5t-wet ($8.5m^3$) of filtered cake is produced per day. Moisture content of the cake is around 47.5%.

(4) Utilization of the Model Plant from now on

Following proposals are made for effective and economical utilization of the plant from the standpoint of overall Ovalle operation. However, some modifications of the plant are needed, on which Chap. 5 of this report is referred to.

1) Volume of feed solution shall be increased to the possible maximum level.

2) When 176m^3 of the waste solution is treated per day, around 10.7t-dry of neutralization sediment with carbonate is produced a day. Wet volume will be about 20.4t-wet/day as 47.5% of moisture is contained. Thus, around 9.7t of water is eliminated out of the operation. This volume corresponds to more than 5% of feed solution to be daily handled. The reduction of this volume of water would prevent heavy accumulation of bacteria metabolite and other metals than Fe in the circuit. Then, neutralization with slaked lime for one tenth volume of the solution, originally designed, is not always necessary. This neutralization with lime shall be operated if necessary, when some metals like Zn and Mn are concentrated abnormally or bacteria activity is reduced.

3) As the result of leaching tests with use of oxidized solution, suitable amount of ferric sulfate promotes Cu leaching. Thus, it is not always necessary in the neutralization step of the model plant to completely neutralize ferric ions. This also saves neutralization cost. However, if complete neutralization is required, pH shall be regulated at 4.0, for example, when clearness of solution is required first or clogging of solution pipes are feared, etc.

4.4 Present and Future of the Model Plant

The following data and information were obtained during the 7th (final) field survey period.

(1) Present situation

Until recently, part of the pregnant (leached) solution was separately treated for recovery of $CuSO_4 \cdot 5H_2O$ as a new product. However, this operation has been suspended due to some difficulty in marketing. Another important change in operation is that the excess waste solution from the Cu precipitation step, which exceeds the model plant capacity, is now sent back to the leaching step for reuse instead of evaporation treatment in the ponds. This could have brought higher concentration of Fe and other metal ions in the waste solution to be fed to the model plant.

The recent operational data of the model plant are obtained as follows.

- Total volume of the waste solution from the Cu precipitation : 220m^3/day
- Feed volume to the model plant : 50m^3/day
- Circulating volume to the leaching step : 170m^3/day
- Fe^{2+} concentration at the inlet of oxidation tanks : 57.3g/L
- Fe^{2+} concentration at the outlet of oxidation tanks : 0.9g/L

As shown above, oxidation with bacteria is satisfactorily realized, though Fe^{2+} concentration of the feed solution is nearly the saturation.

(2) Future

Current operation cost at the model plant is around US$ 13,000～15,000/month including labor cost. It is urgent to reduce this operation cost. For this purpose, caustic soda is now being introduced as a neutralizer on a trial for calcium carbonate to recover any salable byproduct like ferric sulfate solution, free from gypsum, as an inorganic flocculent, which could be used in waste water treatment. Commercial and economic situation are yet to be studied.

4.5 Instructing Subjects for Technology Transfer

The following technical items were transferred throughout the Study period.

(1) Cultivation Method of Iron Oxidizing Bacteria

1) Liquid culture
2) Plate culture
3) Subculture

(2) Counting Method of Iron Oxidizing Bacteria

1) Direct count
2) Culturing count

(3) Continuous Oxidation Tests with Use of Iron Oxidizing Bacteria

1) Mass cultivation of bacteria
2) Forming bacteria carrier
3) Test program, conditions, data collecting and analyses

(4) Neutralization Tests

1) Neutralization curve
2) Required amount of neutralizer and volume of sediment
3) Settling tests
4) Filtering tests

(5) Demonstration Tests at the Model Plant (for waste solution treatment)

1) Test conditions
2) Analytic methods
3) Data collection and analyses

1) Leaching-cementation Process Effluent

2) Bacterial Oxidizing Process

3) Bacterial Oxidizing Tank

4) Oxidized Solution

5) Filter Press Cake

6) Bacterial Sludge and Neutralized Sediment

7) Feed and Treatment Solution

8) Reuse to Leaching Plant

５. Design of Full Scale Solution Treatment Plant

5. Design of Full Scale Solution Treatment Plant

5.1 Prerequisites for Design

5.1.1 Size of the Plant

Currently, volume of the waste solution from the leaching step of Ovalle plant is around 250m^3/day corresponding to about 6,000 t/month of crude ore. As the installed capacity of the plant is now 14,000t/month, which will bring about 600m^3/day of the waste solution when fully operated. As a matter of fact, however, crude ore supply for the operation has declined recently due to lower price of Cu and 8,000t/month of the ore supply is expected at most for the time being, if some price incentives were given to the suppliers.

Considering the recent situation plant design was made in two different levels of monthly throughput, one corresponds to the maximum treatment at the leaching step, 14,000t/month, and another is 8,000t/month, which is practically more realizable. The volume of the waste solution to be treated is estimated as shown in Table 5-1.

Table 5-1 Volume of Waste Solution to be Treated

	Monthly ore tretment	Volume of Waste Solution
Current situation	6,000 t/month	250 m^3/day
Case 1	8,000 t/month	330 m^3/day
Case 2	14,000 t/month	600 m^3/day

5.1.2 Specification of the Waste Solution

Specification of the waste solution tobe fed to the treatment plant is set as follows.

Table 5-2 Specification of Waste Solution (g/L)

pH	Fe^{2+}	T-Fe	Cu	Mn	Zn	Al
3.3	17.02	20.66	0.108	0.507	0.208	2.77

5.1.3 Oxidation Velocity

As oxidation velocity, 1.0g/L/h is employed as the results of the demonstration tests.

5.1.4 Volume of Sediment

From the test results, volume of sediment was 8.54m^3/day, or 12.46wet-t/day, when 100m^3/day of waste solution was fed to the plant. Average moisture content of the sediment is 47.5%.

5.1.5 Process Flow

Outline of the process flow is illustrated in Figure 5-2, which excludes pH adjustment step in the model plant.

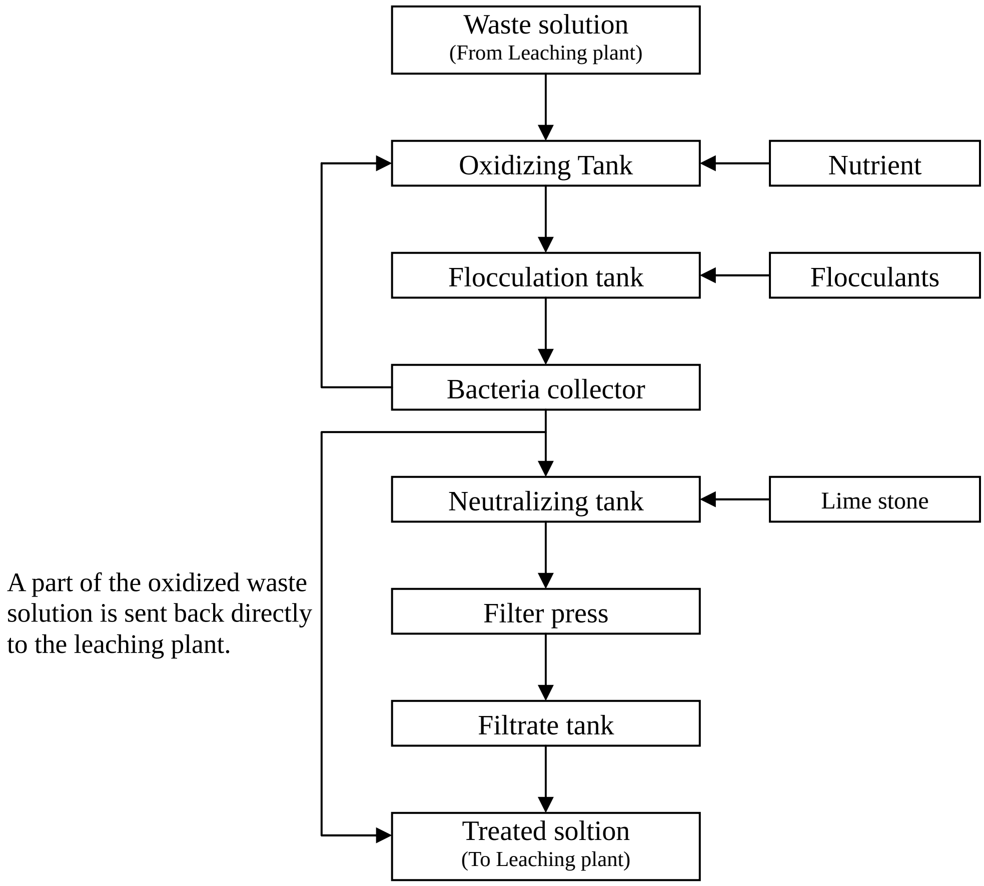


Figure 5-1 Process Flow of Full scale Plant

5.1.6 Capacity of the Model Plant

This model plant was originally designed to treat the solution, of which specification is shown in Table 5-3. Concentration of ferrous ion is down now to around 17g/L, nearly half level of the original.

Table 5-3 Specification of Feed Solution for Model Plant Design (g/L)

pH	Fe^{2+}	T-Fe	Cu	Mn	Zn	Al
3.7	30	30	0.26	0.97	0.24	9.7

Total volume of the filtered cake is also reduced to 12.46wet-t/day, from about 31.5 wet-t/day, originally designed. This allows more capacity of the major equipment like oxidation tanks and filter press than originally designed, 100m^3/day. Thus, the model plant could increase its capacity up to about 176m^3/day with simple modification listed in Table 5-4.

Table 5-4 Necessary Modification in the Model Plant

ITEM No.	Equipment Name	Model plant					Remodeling point
		Specification of Equipment		Power (kw)	Q'ty		Specification of Equipment
P1	Waste solution pump	Type : Capacity : Material :	Centrifugal pump 84L/min×20mH Contact surface with solution SUS316,SCS14	1.5	1		Necessary having to change equipment It is assumed the ability to amount 176m^3/day of the waste solution. Therefore, piping and the change of the flow instrument are needed as 123L/min×20mH ×2.2kw and the pump change.
P10	Transportation pump after neutralization	Type : Capacity : Material :	Centrifugal pump 100L/min×20mH Contact surface with solution SUS316,SCS14	2.2	1		Necessary having to change equipment The filtrate amounts become about 32m^3 by one time, and this pump needs the ability of 1200L/min which corresponds to the press fit pump because Filtrate tank is not sufficient as the buffer is needed in the above-mentioned filtrate-tank capacity. Moreover, because the pH adjustment process became unnecessary, this pump sends treated solution back directly to the leeching plant. Therefore, the change in piping is needed as 1200L/min×45mH×22kw pump changes.

5.1.7 Necessary Treatment Capacity for New Facilities

According to the above discussion, the existing model plant can be modified to treat up to 176m^3 of the solution per day with no major change. This means the new facilities to be installed should be sufficient if they were able to treat the following solution volume.

Case 1 : 8,000t-ore/month (corresponding to the maximum ore supply, currently possible)	154 m^3/day
Case 2 : 14,000t-ore/month (corresponding to the installed capacity of the leaching plant)	424 m^3/day

In the following section, design is outlined in each case.

5.2 Outline of Full Scale Plant Design

5.2.1 Case 1 (corresponding to the maximum ore supply, currently possible)

In this case, required capacity to be newly installed is 154m^3/day as stated in 5.1.7. (total solution volume to be treated : 330m^3/day). As for a major equipment, filter press, the existing one has already sufficient capacity and can be placed with no difficulty. Accordingly in this case, modification of the existing model plant was mainly studied.

(1) Study on Major Equipment

Equipment newly installed or modified for the new solution treatment plant is listed in the following Table 5-5. (Equipment to be installed is shown with N after its number.)

Table 5-5 List of Equipment to be Installed or Modified in Case 1

ITEM No.	Equipment Name	Specification of Equipment		Power (kw)	Q'ty	Remarks
	Oxidizing process					
P1	Waste solution pump	Type : Capacity : Material :	Centrifugal pump 230L/min×20mH Contact surface with solution SUS316,SCS14	2.2	1	The equipment of the model plant is changed.
T2-N	Oxidizing tank	Type : Capacity : Material : Dimension :	Vertical cylinder with internal baffle 75 m^3 FRP 4290ϕ×5900H		2	
T4-N	Bacteria collector	Type : Dimension : Material : Accessories :	Thickener 2600ϕ×2500H FRP Rake	0.75	1	
B1-N	Oxidizing blower	Type : Capacity : Material :	Roots blower 12.95 m^3/min×7000mmAq FC etc.	30 0.2	1	
T5-N	Bacterial-sludge storage tank	Type : Capacity : Material : Dimension :	Vertical cylinder with internal baffle 1.8 m^3 FRP 1300ϕ×1650H		1	
M2-N	Agitator for Bacterial-sludge storage tank	Type : Material :	Paddle Contact surface with solution SUS316	1.5	1	
P3-N	Bacterial-sludge feed pump	Type : Capacity : Material :	Centrifugal pump 300L/min×40mH Contact surface with solution FC+R/L	11	1	The press fit pump in the model plant pH adjustment process is diverted.

ITEM No.	Equipment Name	Specification of Equipment		Power (kw)	Q'ty	Remarks
	Neutralizing process					
T11-N	Neutralizing tank	Type :	Vertical cylinder with internal baffle		1	
		Capacity :	6.4 m^3			
		Material :	FRP			
		Dimension :	1350ϕ×5150H			
B2-N	Neutralizing blower	Type :	Roots blower	3.7	1	
		Capacity :	0.67 m^3/min×6000mmAq			
		Material :	FC etc.			
P10	Transportation pump after neutralization	Type :	Centrifugal pump	22	1	
		Capacity :	1200L/min×45mH			
		Material :	Contact surface with solution SUS316,SCS14			

(2) Process Flow

Process flow including the model plant is illustrated in Figure 5-2.

(3) Layout

Layout of equipment including the model plant is shown in Figure 5-3.

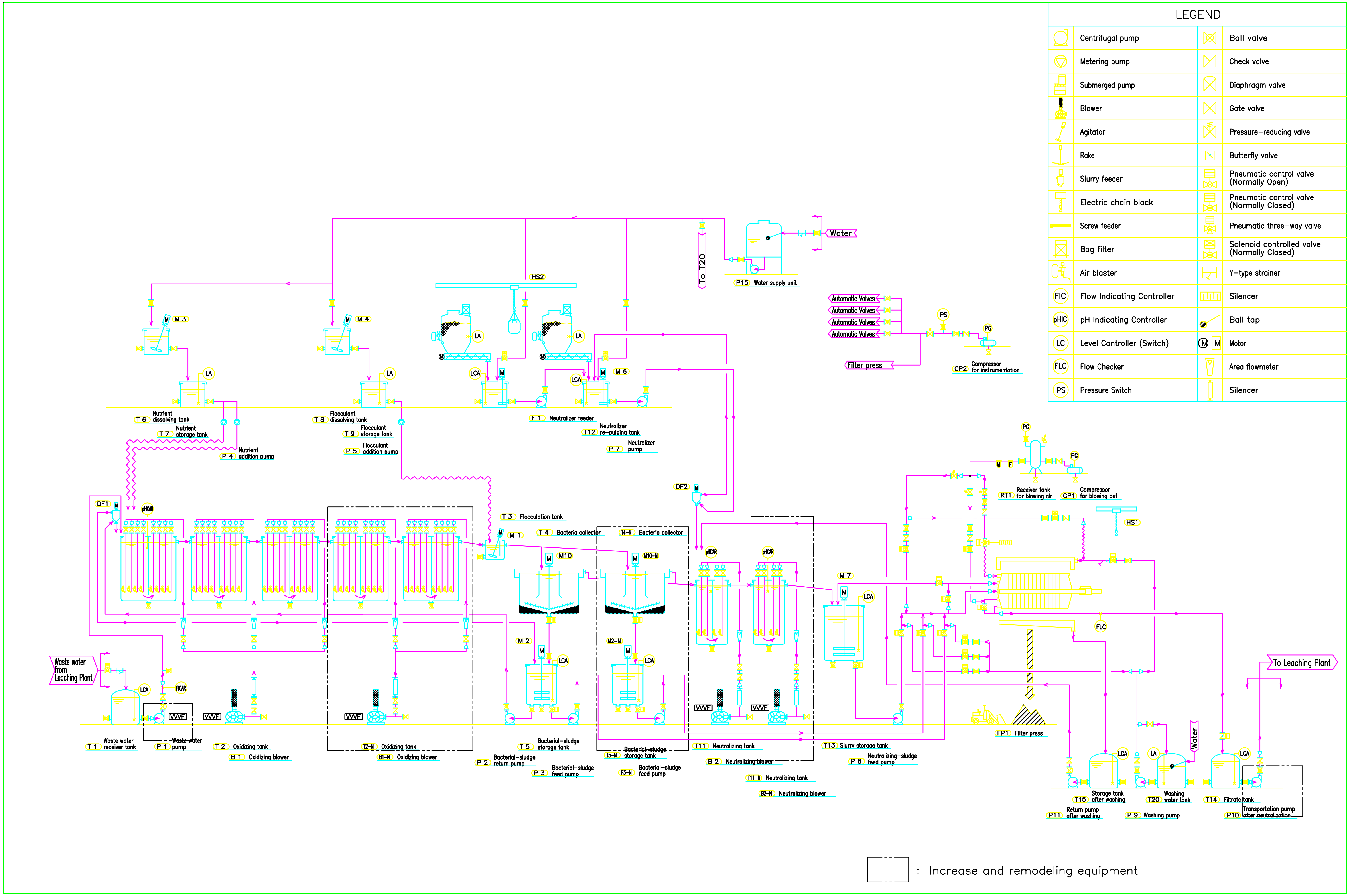
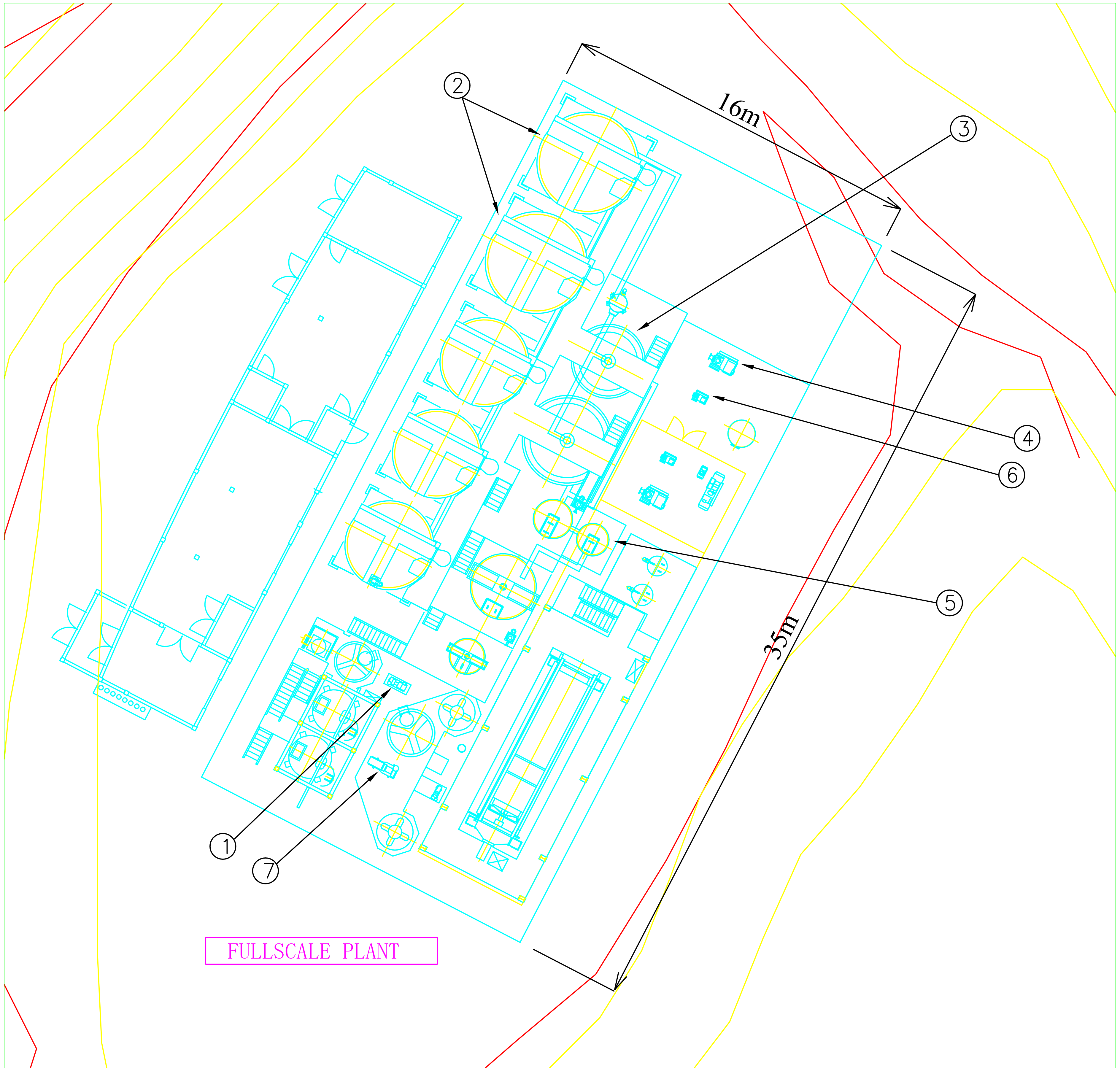


Figure 5-2 Flowsheet of Fullscale Plant (Case1)



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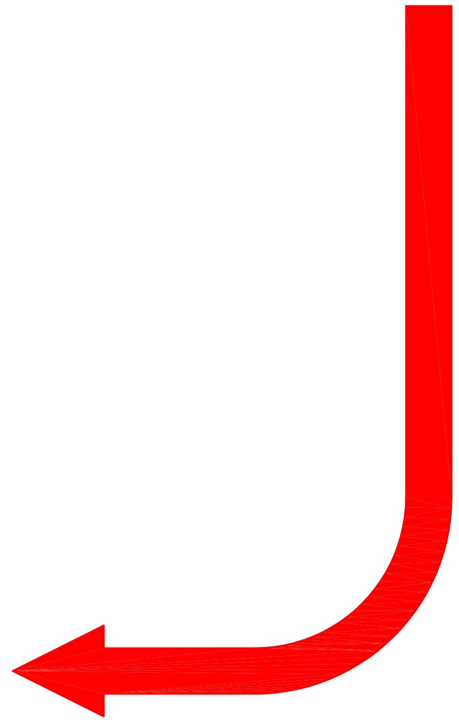


1	P 1	Waste water pump (Change)
2	T 2 – N	Oxidizing tank (New)
3	T 4 – N	Bacteria collector (New)
4	B 1 – N	Oxidizing blower (New)
5	T 1 1 – N	Neutralizing tank (New)
6	B 2 – N	Neutralizing blower (New)
7	P 1 0	Transportation pump after neutralization (Change)

Figure 5-3 Plot Plan of Fullscale Plant (Case1)

5.2.2 Case 1 (corresponding to the maximum installed capacity)

Necessary facilities for 424m^3 of solution treatment total 600m^3 per day are studied. In this case, one additional filter press and some oxidizing tanks are required to meet the increased volume of solution. These equipment shall be installed newly close to the existing model plant.

(1) Study on main equipment

The following Table 5-6 shows equipment list to be newly installed in case 2.

Table 5-6 Equipment List to be Installed in Case 2

ITEM No.	Equipment Name	Specification of Equipment		Power (kw)	Q'ty	Remarks
T2	Oxidizing tank	Type : Capacity : Material :	Corner tank (internal division into four) 413m^3 RC+FRP/L		1	
T4	Bacteria collector	Type : Dimension : Material : Accessories :	Thickener 4800ɸ×2500H FRP Rake	1.5	1	
B1	Oxidizing blower	Type : Capacity : Material :	Roots blower 37.2m^3/min×7000mmAq FC etc.	75 0.75	1	
T11	Neutralizing tank	Type : Capacity : Material :	Vertical cylinder with internal baffle 20.4m^3 FRP		1	
F1	Neutralizer feeder	Type : Capacity : Material : Accessories :	Screw feeder 3500kg/h SS Air blaster, Bag filter	3.7 0.75	1	
B2	Neutralizing blower	Type : Capacity : Material :	Roots blower 2.2 m^3/min×6000mmAq FC etc.	7.5	1	
FP1	Filter press	Type : Capacity : Material :	Automatic type Filtration area 203 m^2 Filterplate PP, Bed FC+R/L Dripping pan SUS316	5.5	1	

(2) Process Flow

Process flow including the model plant is illustrated in Figure 5-4.

(3) Layout

Layout is also illustrated in Figure 5-5 including the model plant.

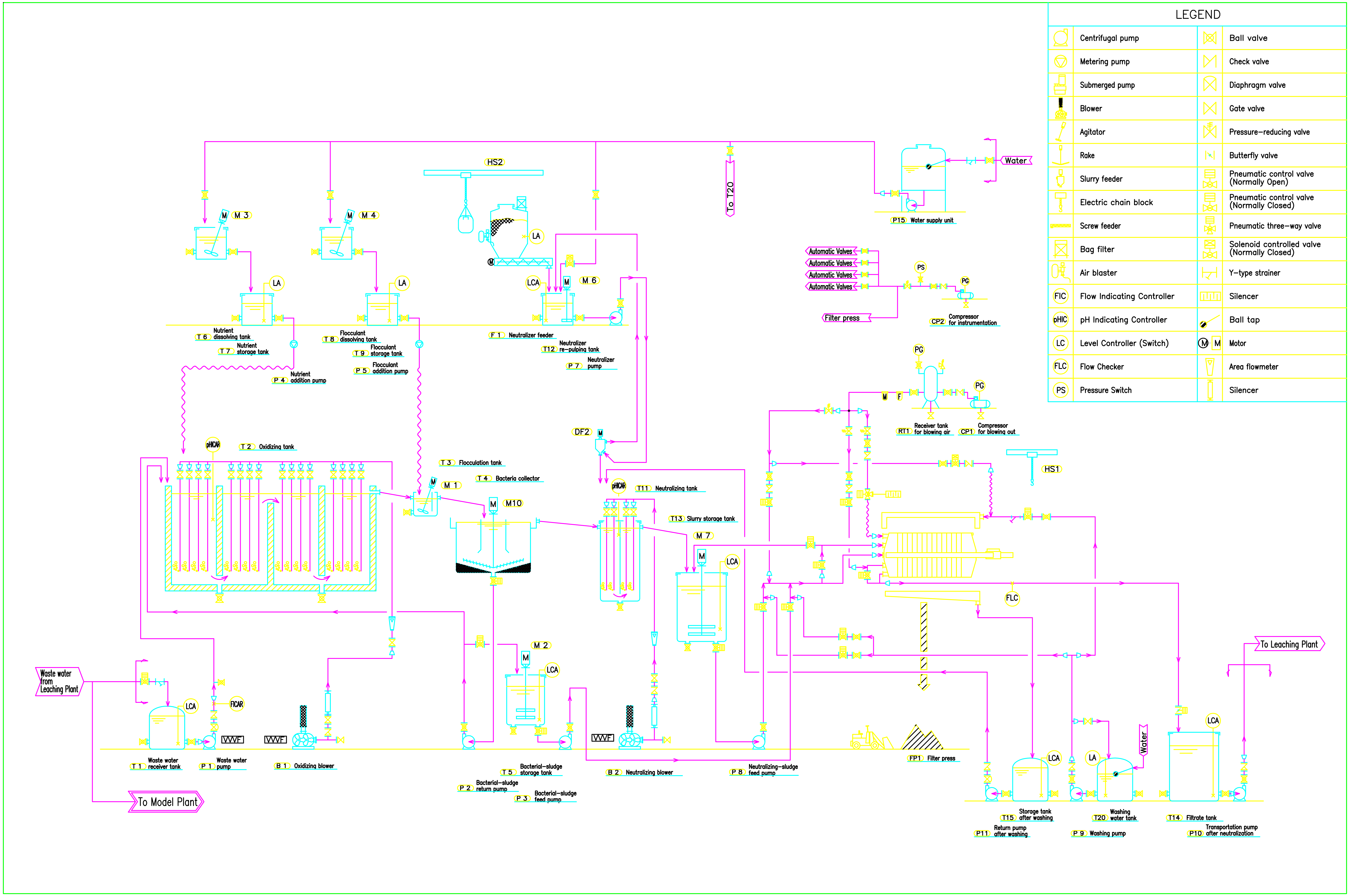
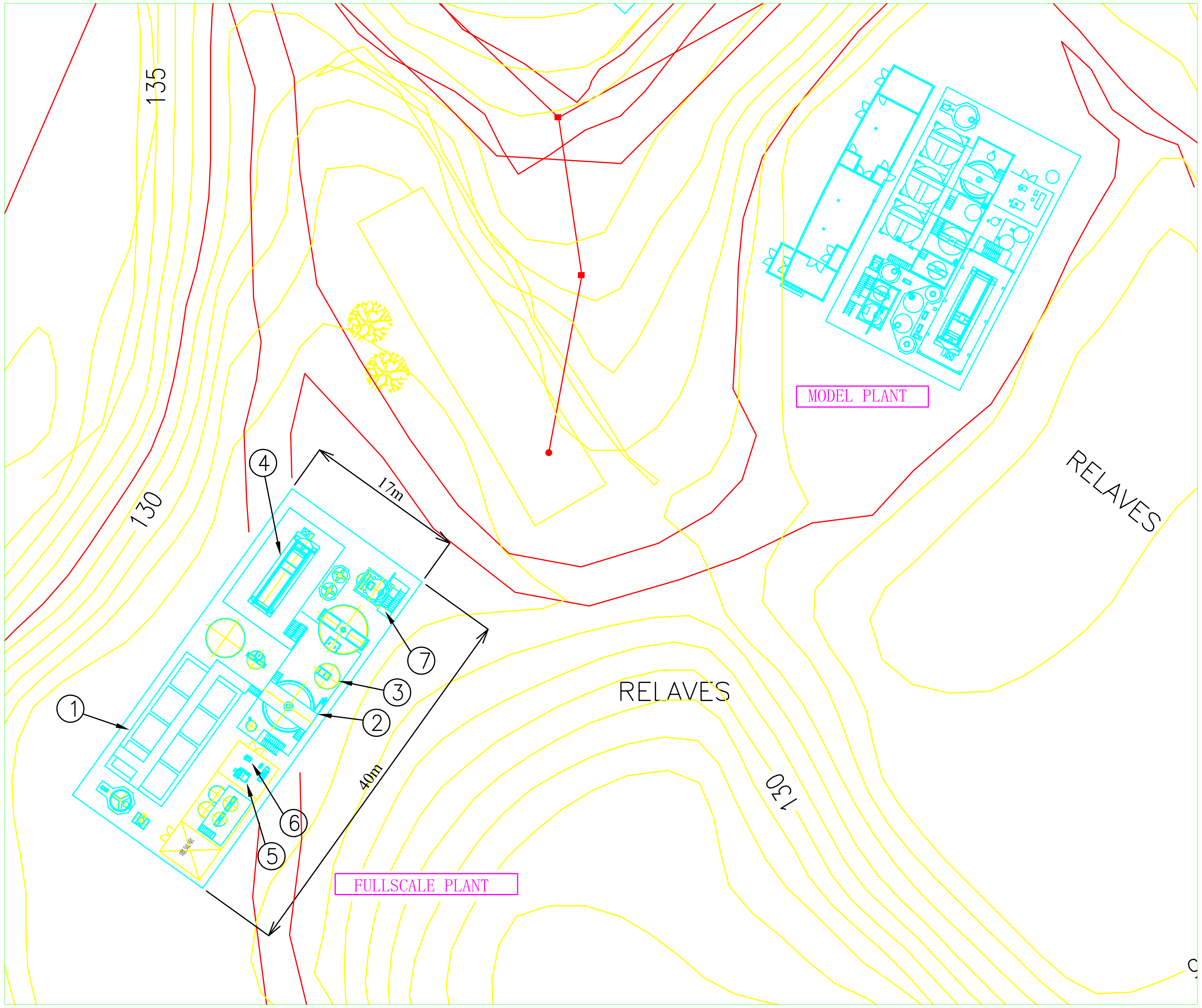


Figure 5-4 Flowsheet of Fullscale Plant (Case2)



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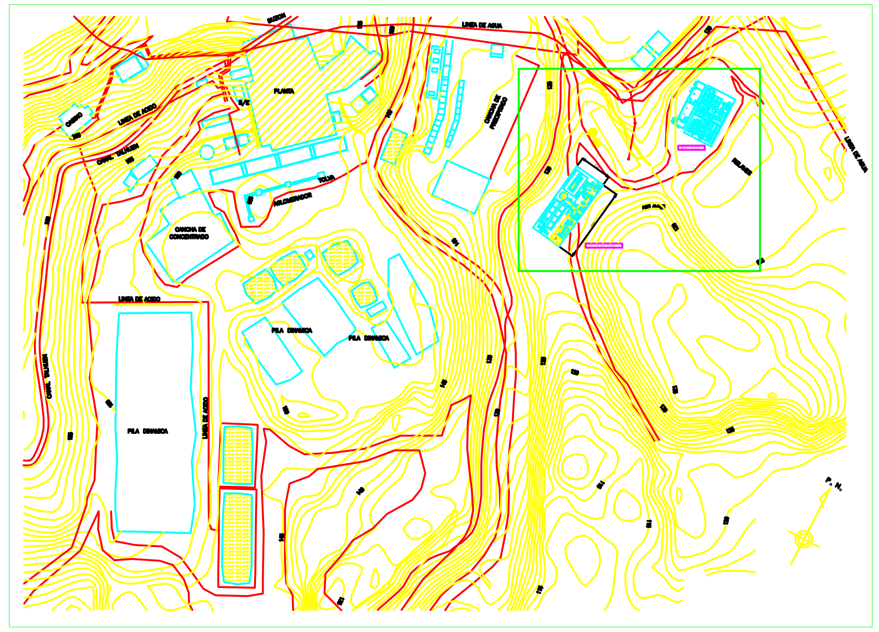

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1	T 2	Oxidizing tank
2	T 4	Bacteria collector
3	T 1 1	Neutralizing tank
4	F P 1	Filter press
5	B 1	Oxidizing blower
6	B 2	Neutralizing blower
7		Neutralizer addition unit

Figure 5-5 Plot Plan of Fullscale Plant (Case2)

5.3 Estimate of Installation and Operation Costs

From the results of above discussion, installation and operation costs for the full scale plant are estimated below. In case 1, cost for modification of the model plant to treat 330m^3/day of the waste solution is shown as installation cost. Also necessary change in the model plant to treat 176m^3 a day was estimated for comparison.

5.3.1 Installation Cost

Installation cost in each case is estimated respectively as shown in the following Table.

（US$）

	The Maximum Capacity of Model plant 176m^3/day	Case1 330m^3/day	Case2 600m^3/day
Mechanical works	35,000	282,000	1,245,000
Electric works	4,000	47,000	354,000
Civil works	0	48,000	416,000
Architectural works	0	22,000	110,000
Amount	39,000	399,000	2,125,000

5.3.2 Operation Cost

Operation cost in each case is estimated respectively as shown in the following Table.

（US$／year）

	The Maximum Capacity of Model plant 176m^3/day	Case1 330m^3/day	Case2 600m^3/day
Material	67,000	126,000	228,000
Electric	26,000	38,000	83,000
Labor	40,000	40,000	40,000
Maintenance	49,000	58,000	96,000
Amount	182,000	262,000	447,000

* Material cost is based upon the following price. As for consumption, refer to the Chap. 4.

    Calcium carbonate : US$ 0.0589/kg
    Nutrient : US$ 4.61/kg
    Flocculant : US$ 4.428/kg

* Electric charge is based on US$ 0.052/KwH.
* All labor cost is based on the present cost at the model plant.
* Maintenance cost is set at 3% of total installation (electric and mechanical). In case of the model plant, total installation cost was US$ 1,600,000.

６． Economical and Financial Analysis for Waste Solution Treatment

６． Economical and Financial Analysis for Waste Solution Treatment

6.1 Background and Outline of the Project

At Ovalle plant, copper (Cu) precipitate is being produced from oxide Cu ores through leaching and Cu precipitation steps. This process is composed of acid leaching step of oxide Cu ore followed by Cu precipitation for iron scrap from the leached or pregnant solution. Refer to Figure 6-1, which shows the operation before this Study started. From the Cu precipitation step, when Cu is reduced or exchanged for iron scrap, waste solution with high content of iron sulfate is discharged. This solution is led to evaporation ponds, located at downstream from the plant, where moisture is evaporated with sunlight and iron sediment stays at the bottom of the pond. But part of the solution penetrate from the bottom into the soil flowing to nearby the river Ingenio, then contaminate the soil and water system surrounding the plant.

To solve the contamination problem, the bottom is usually lined with waterproof materials, however, this might be insufficient at Ovalle, where earthquake or flood is possible to happen. For prevention of water pollution, this Study was aimed at installation of a model (pilot) plant for neutralization of the waste solution with help of bacteria activity. As the results of demonstration tests at the model plant, it was found that iron components contained in the solution were successfully removed as chemically stable sediment and the effluent can be returned to the previous leaching section and reused. Thus, at Ovalle plant, pollution free operation is assured for oxide Cu ore processing.

On the other hand, production of Cu sulfate was started through a new circuit branched off the main Cu precipitation producing line. In stead of exchanging Cu for iron, it is extracted with organic solvent to crystallize as $CuSO_4 \cdot 5H_2O$ as a saleable by-product. At the same time, the total volume of the waste solution to be treated is correspondingly reduced.

In this Chapter, a feasibility study shall be made when the above model plant is scaled up for industrial use to meet the larger volume of waste solution from the leaching section. Discussion is made in the following three cases of different levels of leaching operation.

- Case 1 : Throughput of the leaching plant is set at 6,000 ton/month. (close to the recent operation and model plant is not scaled up)【*without project*】
- Case 2 : Throughput of the leaching plant is set at 8,000 ton/month (maximum level of the recent operation)
- Case 3 : Throughput of the leaching plant is set at 14,000 ton/month (The maximum capacity)

In the case 2 and 3, of which throughput is over current 6,000 ton/month level, investment is indispensable for increase in volume of waste solution.

Based on the above, economical and financial analyses are proceeded utilizing both private and social evaluation process according to the “Norms and Procedures for Project Evaluation”[1)]

[1)] Standars for application of investment program, CODELCO-ENAMI inside ENAMI. The results of the plant examination, separately carried out in this Study, are also taken into account in the evaluation.

6.2 Procedure for Project Approval

Inside ENAMI, every project (including expansion plan of existing facilities) is discussed and planned based upon the above Norms and Procedures for submission to the Board of Directors, where its feasibility is judged technically and economically. Then, for drawing up next year's budget, discussion is made comprehensively at COCHILCO and MIDEPLAN as illustrated in Figure 6-3. Upon approval by both organizations, it is finally approved through the Congress as national budget.

Throughout the discussion, technical feasibility is confirmed by COCHILCO with use of estimated Cu price, while MIDEPLAN justifies the project in the viewpoint of possible development of natural resources evaluating the relationship with coexisting sectors.

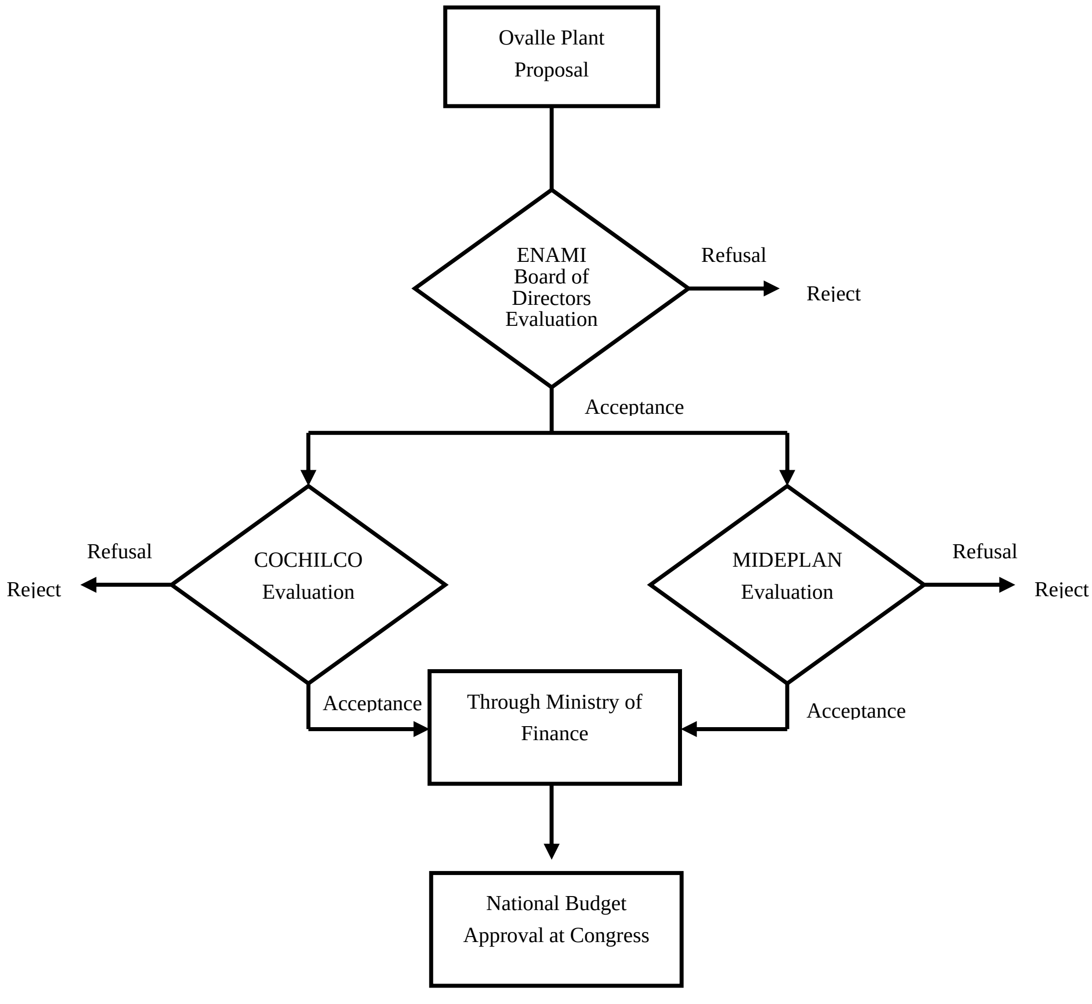

Figure 6-1 ENAMIs Projects Approval Process

6.3 Market and Production Process

Market situation of Cu precipitate as well as Cu sulfate ($CuSO_4 \cdot 5H_2O$), products from Ovalle plant, is summarized as below.

(1) Cu precipitate

As usual Cu grade of this product is 65～85%, further metallurgical treatment is needed in smelting process. This has higher grade than Cu concentrate but less favorable for exothermic reaction in a roasting process, the first step of usual pyrometallurgical treatment.

At ENAMI smelters, Cu precipitate is added into converters (*Pierce-Smith* type) acting a part of temperature regulator, other than copper recovery itself. Ventanas smelter can handle 5,000 tons of Cu precipitate a year (1.25% of total input) , while Paipote smelter 6,000 tons totalling 11,000 tons/year for both smelters. In the year 2000, about 1,200 tons was demanded from outside ENAMI, that means the maximum consumption of this product is about 12,200 metric tons a year inside Chile. As export is unlikely, total amount is for domestic consumption only.

On the other hand, Cu precipitate is being supplied by ENAMI's oxide Cu plants, small and medium producers supported by ENAMI and other independent producers. As indicated in Figure 6-4 and Table 6-1, supply of Cu precipitate has declined as Cu price went down. Thus, the supply will be moving with Cu price in future.

In the year 2000, 62% of this product is from ENAMI's processing plants (El Salado, Taltal, Ovalle and Vallenar) and the rest, 38% is from the third party, outside suppliers. It is assumed that ENAMI plants have 11,800 dmt of production capacity a year in total considering 45% of actual rate of plant capacity utilization in 2000 (out of 11,800 dmt, Ovalle has 3,200 dmt a year). Also ore throughput of each plant is subjected to supplying capacity of surrounding mines. Thus, the rate of capacity use has been decreased at each plant as Cu price declined.

On the other hand, El Salado plant is planning to introduce solvent extraction and electro-winning process (SX-EW) to produce electrolytic Cu as a final product instead of Cu precipitate. Test operation of SX-EW has already been completed on a small scale (55t/month), producing electrolytic Cu (grade 99.996%) successfully.

Considering the treatment capacity of ENAMI smelters and production cut at El Salado plant, production increase of Cu precipitate at Ovalle is practically realizable if crude ores are sufficiently supplied. In other words, 3,200 dmt of the maximum yearly production from Ovalle can be well handled at the smelters.

(2) Copper sulfate ($CuSO_4 \cdot 5H_2O$)

Cu content of this product is 26%. Ovalle plant has 40ton of monthly production capacity and this total amount is now exported through a dealer to Rumania. Ex-work price at the plant is 98 ¢ /lb $_{\text{of Cu}}$ (US\$561.73/dmt$_{\text{of CuSO4}}$). On the other hand, production cost is around US\$280/dmt$_{\text{of CuSO4}}$. Currently, 100 tons/month is demanded by the customer.

Worldwide demand of this product is supposed to be around 200,000 tons a year, of which three quarters are for agricultural use, pesticide. Number of producers[4)] worldwide amounts to one hundred or more supposedly. Other uses are various, like electrolyte in copper refining, coating agent in Cu plating, activator in Zn flotation, etching agent of Cu plate, anti-rust paint, glass coloring and others.

6.4 Executing Program

For the scale up plan of the current waste solution treatment (model) plant, the plant life shall be set at 15 years at this moment. Adding one year for construction period, yearly program shall be made for 16 years in total as a project term. Although the positive ore reserves last no more than 11.1 years, as stated in item 1) Crude ores of this section, these are assumed to steadily increase as necessary.

On the other hand, plant closure is not taken into consideration because legal regulations are uncertain yet and will not affect the plant scale to be compared.

Ovalle processing plant is defined as “Custom beneficiation plant”, which adds some value to the crude ores through treatment, and its income and expenditure are evaluated based upon the internal rules of ENAMI. The evaluation methods for oxide Cu ores are studied.

Executing program in future for oxide ore processing is illustrated in Figure 6-2.

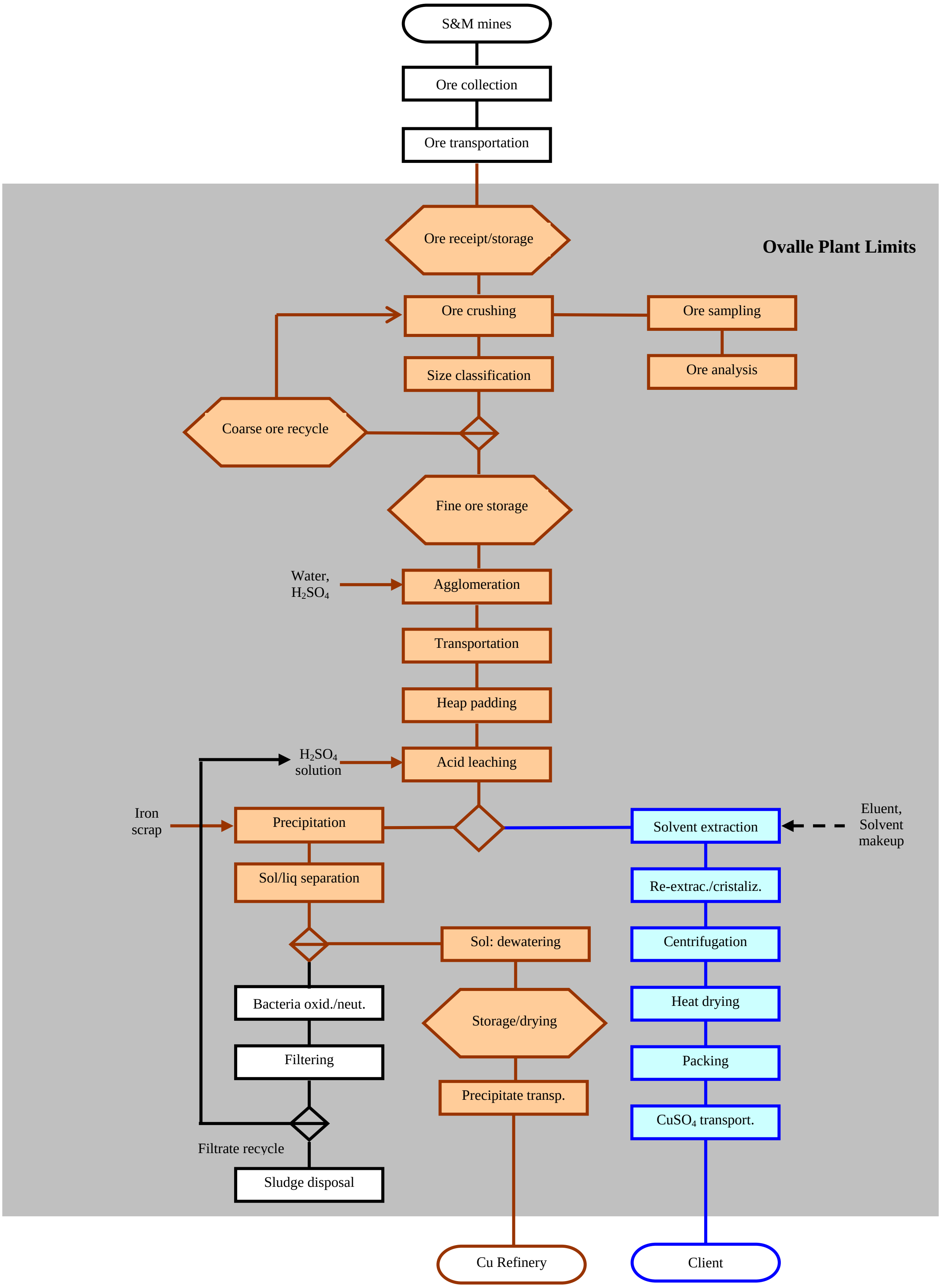

Figure 6-2 Oxide Copper Ore Treatment Process at Ovalle Plant (Future)

6.5 Financial Analysis

From the results of cash flow, discounted cash flow analysis is carried out with use of 14% of discount rate (designated in the "Norms and Procedures for Project Evaluation") to estimate "Net Present Value (NPV)" and "Internal Return Rate (IRR)" as well. These results are summarized in Table 6-1.

Table 6-1 Financial Analysis Results

Project case	Cu price (US ¢ /lb)	Initial investment (thousand US$)	Cash cost* (US ¢ /lb)	$NPV_{14\%}$ (thousand US$)	IRR (%)
Without project	68.2180	139	63.03	-3,484	irrational
6,000dmt ore processing	68.2180	139	59.43	-2,998	irrational
6,000dmt ore processing	80.00	139	59.43	-2,913	irrational
6,000dmt ore processing	92.00	139	59.43	-2,818	irrational
6,000dmt ore processing	102.00	139	59.43	-2,740	irrational
8,000dmt ore processing	68.2180	499	52.70	-3,114	irrational
8,000dmt ore processing	80.00	499	52.70	-2,999	irrational
8,000dmt ore processing	92.00	499	52.70	-2,868	irrational
8,000dmt ore processing	102.00	499	52.70	-2,761	irrational
14,000dmt ore processing	68.2180	2,225	43.93	-3,776	irrational
14,000dmt ore processing	80.00	2,225	43.93	-3,567	irrational
14,000dmt ore processing	92.00	2,225	43.93	-3,331	irrational
14,000dmt ore processing	102.00	2,225	43.93	-3,137	irrational

* First year *Cash Cost* (depreciation cost subtracted operating cost【unit: US ¢ /$lb_{\text{Cement copper Cu content}}$】)

As can be seen from the Table, all the cases are financially infeasible. By increasing throughput level from 6,000 to 14,000dmt per month, cash cost is reduced by about 26% from US ¢ 59.43 to US ¢ 43.93/lb enjoying scale-up merit, however, still insufficient to balance profit and loss. Major problem lies in operation costs brought from the treatment plant of waste solution. Further, effect of the increase of Cu price is so small under current evaluation process that no direct advantages are available. Thus, if Cu price is up from US ¢ 68.2180/lb by about 50% to 102.00 ¢ /lb, effect on NPV comes out only about 9～17% (9, 11 and 17% in Case 1, 2 and 3 respectively) much less on IRR, meaningless.

On the other hand, according to Cu purchasing terms by ENAMI, standard price for oxide ores is US ¢ 17.31/lb and smelting and refining charges (standard) are US ¢ 3.18/lb and 8.80 respectively. With use of these prices, the above-mentioned cash costs in Ovalle are summarized as indicated in Table 6-2.

Table 6-2 Metallic Copper Process Value Added Analysis

	6,000dmt/month	8,000dmt/month	14,000dmt/month
Cu ore basic cost (US ¢ /lb)		17.31	
Ovalle Plant *Cash Cost* (US ¢ /lb)	59.43	52.70	43.93
Smelting charge (US ¢ /lb)		3.18	
Refining charge (US ¢ /lb)		8.80	
Total (US ¢ /lb)	88.72	81.99	73.22

Total amount listed in the above Table corresponds to overall cash flow in ENAMI's Cu production. Although this procedure is different from normal method of financial analysis, it is explained that the financial feasibility throughout ENAMI depends upon the operation scale at Ovalle plant proportionally. In other words, the prerequisite condition to keep Ovalle plant feasible is that Cu price is over US ¢ 88.72/lb at 6,000 ton/ month level of operation and over US ¢ 73.22/lb at 14,000 ton/month respectively.

Another factor to be noticed is difference in smelting charge that is imposed on plant products. Compared to US ¢ 1.00/lb-cu imposed on Cu concentrate, US ¢ 3.18/lb-cu is imposed or charged in case of Cu precipitate despite higher grade of Cu. The difference of US ¢ 2.18/lb-cu has not a little influence on production of Cu precipitate. On the other hand, it is clear from this analysis that Cash Cost attributed to Ovalle is as high as 60～67% of all.

6.6 Economic Analysis

These analyses are based upon shadow price factor, designated by social analytic evaluation in the "Norms and Procedures for Project Evaluation" of ENAMI, application of social discount rate, outside economic effects brought by environmentally friendly operation at Ovalle and entire quantitative analysis within the community including the ore supplying miners.

The shadow price is designated to multiply any income of foreign currency by 1.04 and also to multiply any labor costs for semi-skilled workers by 0.65 as conversion factors respectively. Thus, sales income by exporting $CuSO_4 \cdot 5H_2O$ to Rumania, and labor costs for semi-skilled workers are amended in the following analyses.

The results of the financial analyses, before mentioned, are estimated with DCF process applying 10% of social discount rate (designated in the Norms and Procedures for Project Evaluation).

Further, the external economy are quantitatively estimated with restoration costs of environmental liabilities, improvement effects of water quality in the El Ingenio river resulted from investment on a industrial waste solution treatment plant and also improvement of soil as well.

As for the restoration costs of the environment, total investment was estimated at around US$ 1,251,300. Among them, investments that have direct relation to the El Ingenio river, are waterproof works inside the evaporation ponds, reclamation works of accumulated iron sediments inside the ponds as well as restoration works against nature destruction. Investment that relates to this economic analysis amounts to US$ 460,800 in total.

Outside effects of the new investment at Ovalle are as follows.

- Net present value of the external economy by land restoration, which covers 200Ha of contaminated area along the river El Ingenio.
- External economy including ore supplying mines brought by trading activity between the plant and miners.
- External economy resulted from water saving at Ovalle by circulating reuse.

These effects are shown characteristically in Table 6-3 on yearly base.

Table 6-3 Externalities Resumes

Externality	Year 0 (thousand US$)	Years 1 to 15 (thousand US$/year)
Benefits due to environmental improvements	800,000	0
Benefits for surrounding S&M mines*		
6,000dmt/month, 92.00US ¢ /lb	0	122
6,000dmt/month, 102.00US ¢ /lb	0	411
8,000dmt/month, 92.00US ¢ /lb	0	162
8,000dmt/month, 102.00US ¢ /lb	0	548
14,000dmt/month, 92.00US ¢ /lb	0	284
14,000dmt/month, 102.00US ¢ /lb	0	960
Benefits due to water recycling savings**		
6,000dmt/month	0	168
8,000dmt/month	0	230
14,000dmt/month	0	202

* Benefit value diverges depending on ore process level and copper price.
** Benefit value diverges depending on ore process level.

The results of economic analysis are summarized in Table 6-4.

Table 6-4 Economic Analysis Results

Project case	Cu price (US ¢ /lb)	Initial investment (thousand US$)	Cash cost* (US ¢ /lb)	$NPV_{10\%}$ (thousand US$)	IRR (%)
6,000dmt ore processing	68.2180	600	54.31	-776	53.68%
6,000dmt ore processing	80.00	600	54.31	-672	47.44%
6,000dmt ore processing	92.00	600	54.31	370	irrational
6,000dmt ore processing	102.00	600	54.31	2,671	irrational
8,000dmt ore processing	68.2180	960	48.13	-92	irrational
8,000dmt ore processing	80.00	960	48.13	51	24.92%
8,000dmt ore processing	92.00	960	48.13	1,445	153.14%
8,000dmt ore processing	102.00	960	48.13	4,516	407.54%
14,000dmt ore processing	68.2180	2,686	39.92	105	11.10%
14,000dmt ore processing	80.00	2,686	39.92	364	13.68%
14,000dmt ore processing	92.00	2,686	39.92	2,814	33.88%
14,000dmt ore processing	102.00	2,686	39.92	8,197	72.64%

* First year *Cash Cost* (depreciation cost is subtracted from operating cost【unit: US ¢ /$lb_{\text{Cement copper Cu content}}$】)

In case of 6,000dmt/month of ore throughput, negative values are shown through NPV evaluation when Cu price is below US ¢ 80.00/lb resulting in socially infeasible project. If the price rose above US ¢ 92.00/lb, NPV value turned positive, while by IRR evaluation method, shown as irrational. This is caused by that investment for large scale of solution treatment is unnecessary and profit-loss exceeds break-even point when Cu price is over US ¢ 92.00/lb. In other words, realization of land restoration is the key factor for continuous plant operation in this case. If Cu price rose above US ¢ 92.00/lb, the operation exceeds the bottom line turning into socially feasible.

In case of 8,000dmt/month, positive value was obtained through NPV evaluation when Cu price is above US ¢ 80.00/lb and also extraordinary high value in IRR analysis. This was brought by comparatively large advantage in the earlier period and good profit-loss balance. Thus, if the price is over US ¢ 80.00/lb, it is socially feasible.

In case of 14,000dmt/month, full scale operation of the current capacity, the operation is far above the bottom line turning into socially feasible by enjoying scale up merit. NPV values are all positive in the range of Cu price between US ¢ 68.2180～102.00/lb, and in IRR analysis, values larger than the social discount rate, 10% are given. Of course, as Cu price rose, situation turns still better.

Further, through the study of investment recovery period, it will be possible within two years when Cu price is US ¢ 102.00/lb and within thirteen years at most with US ¢ 68.2180/lb of the price.

6.7 Economic Effects for the Third Party (Cu Precipitate Producers)

For the purpose of judging the price evaluation, which is diffused inside ENAMI, estimation was made on added value of Cu precipitate for comparison, when produced by the hand of a private miner or the third party by itself.

These results show that the added values of Cu precipitate stay lower than Cash Cost born by Ovalle plant. In other words, the third party or outside producers of Cu precipitate can not enjoy the added value when produced it by themselves. Nor can they enjoy increase in Cu price due to unbalanced price system between crude ore and Cu precipitate.

Accordingly, as long as the price evaluation by ENAMI is valid, it is more favorable for the outside producers to sell oxide ores as they are or before producing Cu precipitate. In other words, added value to precipitate is economically disadvantageous.

6.8 Conclusion on Economical and Financial Analysis

The results of the financial and economic analyses are summarized for final recommendation as follows.

6.8.1 Increase in Capacity Utilization Rate for Oxide Cu Processing

Usual NPV or IRR evaluation resulted in “infeasible” in every case, however, Cash Cost are found to be remarkably reduced by increasing the rate of capacity use. On the other hand, economic analyses including outside effects resulted in feasible operation in the case of 14,000 dmt/month of ore throughput even at lower level of Cu price.

6.8.2 Increase in Stable Supply of Oxide Cu Ores

For the improvement of capacity use rate, stable supply of crude ores is inevitable. For this purpose, it is necessary to tie up with any specific ore suppliers or to develop mining program by Ovalle itself, though this involves some change in the business affairs stated in the Articles of Association.

On the other hand, it was understood that the cost of ore procurement is now US ¢ 17.31/lb-cu, accounting for more than 20% of the total. Switching this fixed cost into variable one is an important problem. This also can be solved by performing own mining operation.

Major business target of ENAMI is offering help and assistance to small and medium miners. However, under recent severe situation, in which crude ores are hardly supplied, some transformation should be discussed from its original role, "supporting system", into new "job creating organization in regional development". Especially, in local areas, where no economic activity is available other than mining, establishment of job creation policy for business expansion is highly recommended.

6.8.3 Scale up of Waste Solution Treatment Plant

As the results of these analytical works, expansion of the waste solution plant is inevitable for treatment of total volume of the waste solution from the leaching step.

Further, by circulating the treated solution from the plant to the preceding leaching step, water for industrial use can be saved as a whole. Although this has not a great economical effect on Ovalle plant, but will contribute to the outside community considerably.

6.8.4 Restoration of the Environmental Liability

Contaminated soil and water caused by the past environmental carelessness have to be solved by any improvement restoration works. They are to be proceeded along with the expansion of solution treatment plant. It is expected that the inhabitants are able to extremely enjoy the results of the restoration works.

6.8.5 Increase in $CuSO_4 \cdot 5H_2O$ Production

This production should be continued or rather increased by surveying the market, since it contributes to diversification of product and decrease in solution volume as well.

6.8.6 Study on Merchandizing of Iron Sediment

Considering the specification of the iron sediments (currently final waste), if these were successfully merchandized as some kind of iron material, they could contribute greatly to diversification of the waste solution treatment plant assuring profitable operation.

6.8.7 Review of Price, Evaluation Standards etc.

Considering the current situation of income and cost allotment, especially underestimated price for Cu precipitate production, it is necessary to review the predetermined Standards again taking real conditions into consideration.

The following Figure summarizes the above recommendations along with resultant advantages.

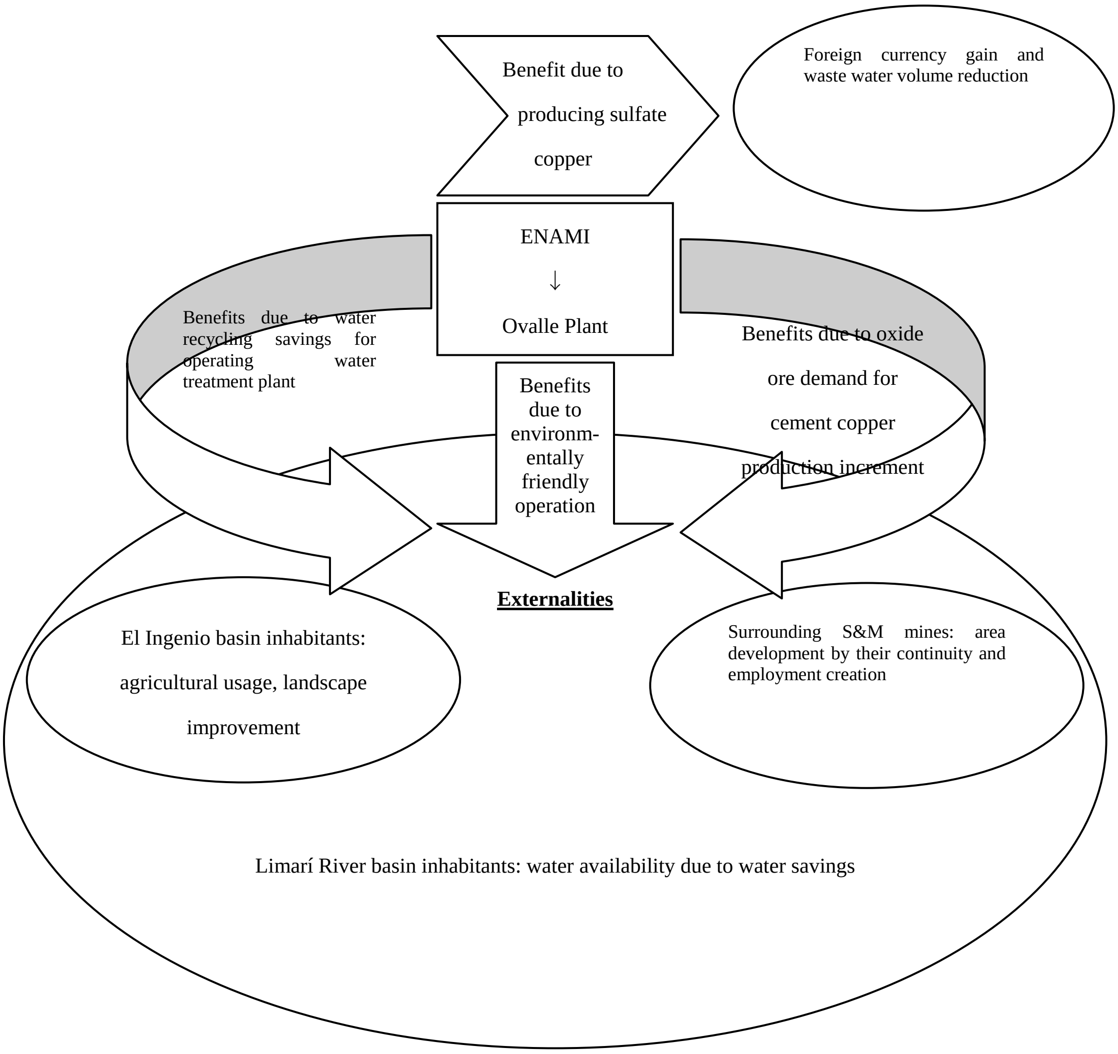

Figure 6-3 Proposal-Benefit Interrelation

７. Environmentally Friendly Operation Plan at Ovalle Plant

7. Environmentally Friendly Operation Plan at Ovalle Plant

In this Chapter, the most desirable operation system at Ovalle discussed in the preceding Chap. 6, is reviewed first in sec. 7.1, and then, more practicable alternative proposed from ENAMI side is discussed in sec. 7.2 as the second best.

7.1 Most Desirable Operation

In the previous Chap.6, the economic and financial analyses were carried out in different levels of monthly throughput of crude ores, that is, recent average of 6,000ton, recent maximum 8,000ton and installed capacity of the leaching plant, 14,000ton. In either case, the operation could be feasible if Cu price is over 92, 80 and 68.218￠/lb respectively. It is necessary to partly modify the present model plant for monthly 6,000ton, to partly reinforce for 8,000ton and to newly install a separate “full scale plant” for 14,000ton respectively for the treatment of total volume of the waste solution from the leaching section. In each case, copper sulfate is produced as a new product prior to the Cu precipitation step and this also contributes to reduction of the solution volume. Among the three cases discussed, monthly throughput of 14,000ton is the most desirable from economical and environmental standpoints. The flow diagram of this “full scale operation” is shown in Figure 7-1.

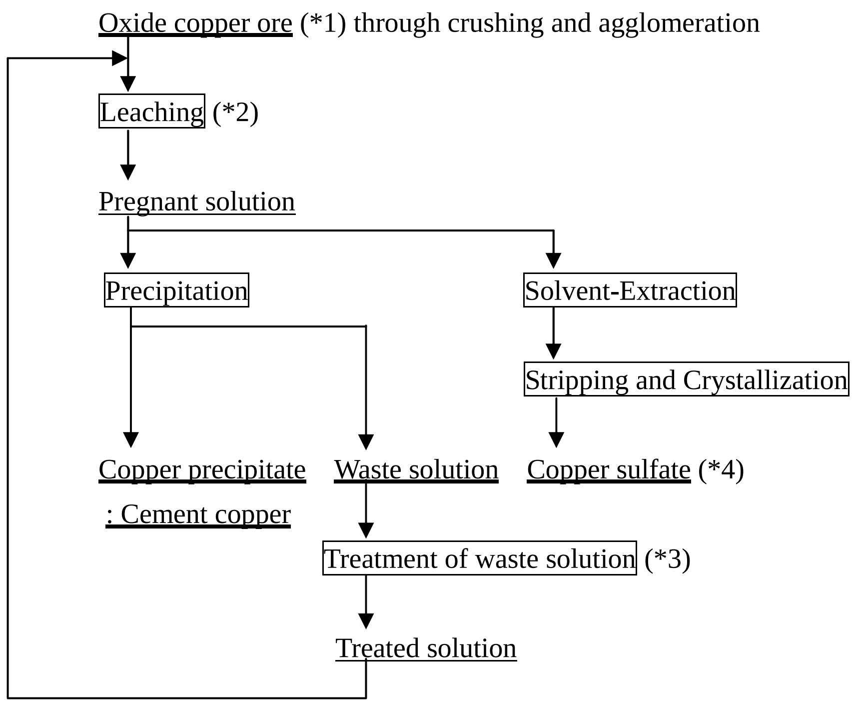

Figure 7-1 The Best Operation Flow Thoughtful to Environment for Oxide Copper Ore

*1：14,000t/month（Full capacity operation）

*2：Leaching composition: primary leaching 52%＋secondary leaching 48%

*3：Full-scale plant with capacity of 600m^3/day may be constructed to treat all waste solution.

*4：Production: 40t/month

7.2 More Practicable Operation

In this section, more practicable and pollution free operation is studied including ENAMI's opinion with the least investment.

7.2.1 Operation Policies by ENAMI (as of March, 2002)

Newly established policies on Ovalle operation are described below.

(1) Processing of oxide ores

① No pollution shall be caused again. → No waste solution shall be discharged from the plant : All solution (treated or untreated) shall be returned to the leaching step for reuse.

② Under the current economic situation in debt, it is impossible for ENAMI to make such heavy investment on the solution treatment newly. The plan shall be abandoned.

③ The existing model plant shall be operated fully, though operation cost is severe. → The rated capacity is 100m^3/day but could handle more.

④ According to the recent results of oxide ore supply, the maximum level is 8,000ton/month (solution volume : 330m^3/day) and averaged 6,000ton/month (250m^3/day).

⑤ Discussion shall be made to reduce the waste solution volume. → One is production of copper sulfate ($CuSO_4 \cdot 5H_2O$) and another is introduction of solvent extraction and electro-winning (SX-EW). The latter is not employed at the moment.

⑥ Discussion shall be made to recover Cu remained in the waste solution. → All solution (treated or untreated) shall be returned to the leaching step.

⑦ Trial for unique product → Production of $CuSO_4 \cdot 5H_2O$ from the pregnant solution (before Cu precipitation).

(2) Processing of sulfide ores : Present operation shall be continued.

7.2.2 Discussion on the Processing Methods

In this section, possible processing methods are studied. The results are summarized in Table 7.1.

7.2.3 Case Study

Possible flows are independently studied in the report.

7.2.4 Operation in Accordance with Current Ovalle Situation

Operation policies in accordance with the present situation are discussed below, combining the above discussion and ENAMI's policy.

(1) Oxide Cu ore processing

1) Prerequisite conditions

① Average throughput (actual level) : 6,000ton/month[72,000ton/year] (capacity utilization rate 43%)

{Maximum throughput (actual level) : 8,000ton/month[96,000ton/year] (capacity utilization 57%)}

② Volume of waste solution : 250m^3/day (actual average) is to be treated.

③ Maximum volume of treatment at the model plant : 176m^3/day

2) Order of priority

Discussion is based on the above condition ①, 6,000ton/month (volume of waste solution : 250m^3/day). Preterable operation flow is as follows. Circled number shows the corresponding operation in the Table 7-1.

{① Leaching → ② Cu precipitation from pregnant solution → ③ Treatment of waste solution at the model plant (treated solution is reused at leaching)} + {① Leaching → ⑫ Solvent extraction of pregnant solution → ⑬ Reverse extraction, crystallization ($CuSO_4$ production)}

Discussion is made in order of priority.

① leaching → precipitation (with iron scrap) : volume of solution treatment : A m^3/day

The maximum treatment is supposed to go up to 176m^3/day at the model plant due to decrease in ferrous ion concentration. Thus, A = 176m^3/day is taken as the maximum.

Treated solution is returned to the leaching step. Neutralization sediments after the treatment could contain a small quantity of harmful metals like arsenic. It is desirable to accumulate these materials in evaporation ponds(correspond to control type final disposal site in Japan), protected from penetration, for final disposal.

② leaching → solvent extraction → $CuSO_4 \cdot 5H_2O$ production : volume of solution reduced through this process : B m^3/day

When 40ton/month of $CuSO_4 \cdot 5H_2O$ is produced, reduction of the volume would be 30m^3/day. Then, 30<Bm^3/day. This product is now under pilot operation. If produced in large scale, it will contribute not only to reduction of solution volume but also to recovery increase of Cu. Market research is indispensable in a long term.

③ leaching → precipitation : Return of waste solution to the leaching step : C m^3/day {= (250 – A – B)} m^3/day. Then, C = (74 – B) m^3/day. Thus, when 40ton/month of $CuSO_4 \cdot 5H_2O$ is produced, B=30 m^3/day and then C = 44m^3/day. If the production is up to 99ton/month, B = 74m^3/day and then C turns 0 (zero).

Table 7-2 summarizes the more practicable operation flows under the current situation.

Table 7-2　Operation Flow Suitable for Present Conditions

：［Oxide copper ore quantity 6,000t/month, soluble copper grade 2.48%(supposition), copper quantity 128t/month］

（Crude ore）→ Crushing → Agglomeration → Leaching → （Pregnant solution）

→ Precipitation → （Copper precipitate） 135t/month, 83.00 Cu-%, 112 Cu-t/month

～ 117t/month, 83.00 Cu-%, 97 Cu-t/month］

→ (Waste solution) → Treatment → Recycle to leaching section

[176m^3/day]

→ Non treatment → Recycle to leaching section

［30～0 m^3/day］

→ Solvent-Extraction(SX-EW) → Stripping and Crystallization → （Copper sulfate）

［40～99t/month, Cu 10～25t/month］

(2)　Sulfide ore processing

Current operation shall be continued.

Target of the operation : 6,300ton/month　　(75,600ton/year) [capacity utilization : 90%].

7.3　Environmentally- Friendly Operation Program

Transition from the former operation flow (causing pollution) to the current one (no pollution) is illustrated in the Figure 7-2.

Table 7-1 List of Treatment Process: Ovalle Plant, ENAMI

1) Treatment of oxide copper ore

- ① Leaching → 〈Pregnant solution〉
  - → ② Precipitation
    - → 〈Copper precipitate (Cement copper)〉
    - → 〈Waste solution〉
      - → ③ Treatment in model plant
        - → 〈Neutralized sediment〉
        - → 〈Treated solution〉
          - → ⑧ Discharge to river
          - → ⑨ Recycle to leaching section
      - → ④ Other treatment 1
        - → 〈By-product 1 : Hematite Fe_2O_3、Ferrite $FeO \cdot Fe_2O_3$〉
        - → 〈Treated solution〉
          - → ⑧ Discharge to river
          - → ⑨ Recycle to leaching section
      - → ⑤ Other treatment 2
        - → 〈By-product 2 : Ferric sulfate $Fe_2(SO_4)_3$〉
        - → 〈Treated solution〉
          - → ⑧ Discharge to river
          - → ⑨ Recycle to leaching section
      - → ⑥ Only oxidizing → 〈Ferric Fe^{3+}〉 → ⑨ Recycle to leaching section
      - → ⑦ No treated
        - → ⑨ Recycle to leaching section
        - → ⑩ Evaporation pond without sealing work
        - → ⑪ Evaporation pond with sealing work → 〈By-product 3 : Ferrous sulfate $FeSO_4$〉
  - → ⑫ Solvent-extraction (SX) → ⑬ Stripping and crystallization → 〈Copper sulfate $CuSO_4 \cdot 5H_2O$〉
  - → ⑭ Solvent-extraction (SX) → ⑮ Electro-winning (EW) → 〈Electrolytic copper (Cathode copper)〉
  - → ⑯ Sale

2) Treatment of sulfide copper ore

- ⑰ Flotation
  - → 〈Copper concentrate〉
  - → 〈Tailing (Waste)〉 → ⑱ Tailing pond
    - → 〈Clarified water〉 → ⑲ Recycle to grinding and flotation section
    - → 〈Sediment〉

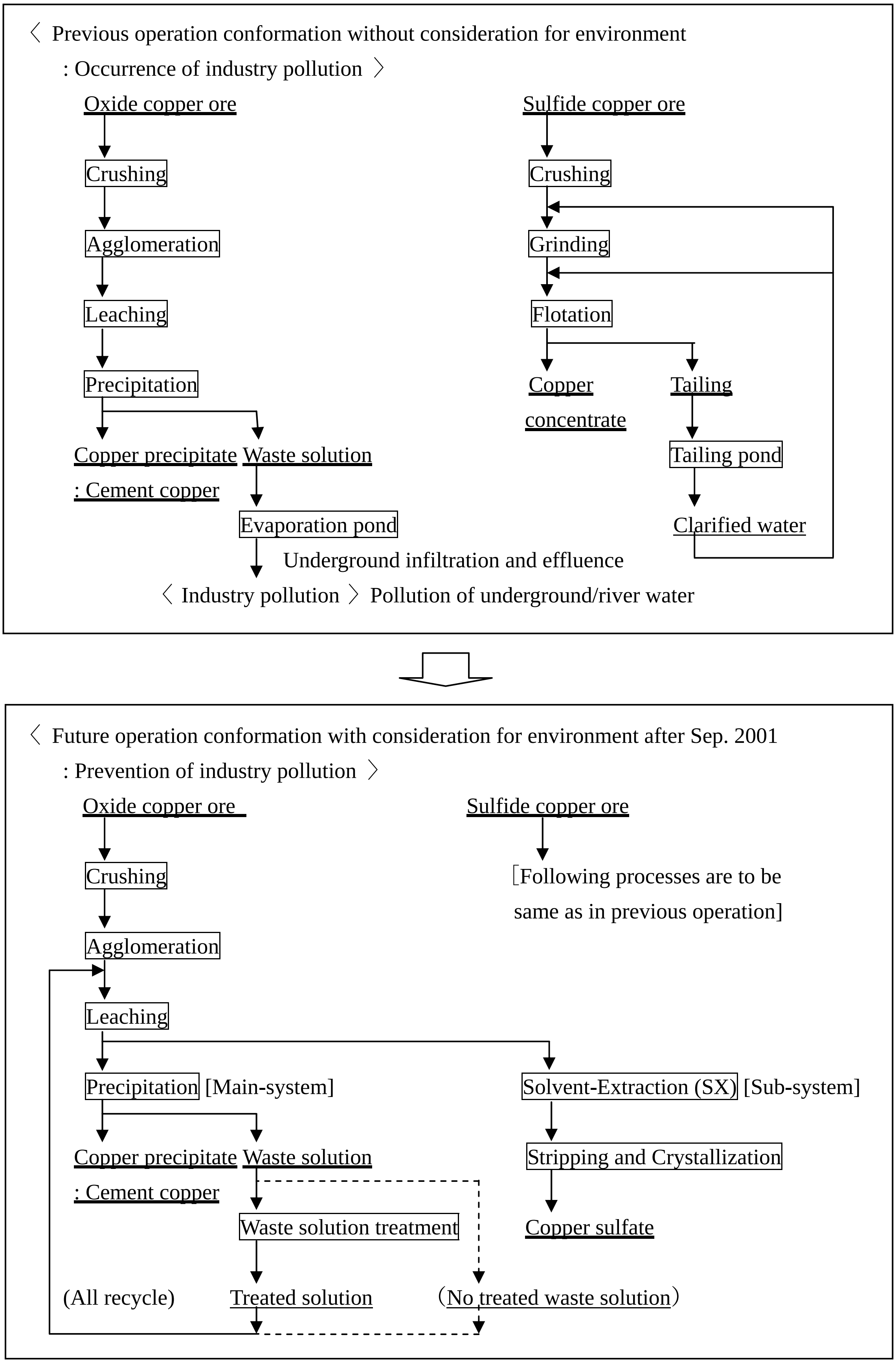

Figure 7-2 Study on the Operation Conformation Flow with Consideration for Environment

８． Possible Application of Bio-Technology in Chile (M/P)

８．Possible Application of Bio-Technology in Chile (M/P)

In this Chapter, discussions are made on whether application of this type of bio-technology is widely accepted in other industrial sites in Chile.

8.1 Outline of Bio-Technology in This Report

Bio-technology employed in this Report is utilization of iron oxidizing bacteria, “Thiobacillus ferrooxidans”, which are capable of oxidizing(*1) ferrous ions into ferric under acidic circumstance. Thus, these bacteria are independent self-nourishing ones, fixing carbon dioxide to grow with use of energy obtained through oxidation.

*1：$2FeSO_4+1/2O_2+H_2SO_4 \rightarrow Fe_2(SO_4)_3+H_2O$ ($Fe^{2+} \rightarrow Fe^{3+}+e^-$)

Application of this bio-reaction to oxidation is superior to that of usual chemical one in achieving environmentally-friendly operation as well as in reducing costs.

8.2 Prerequisites for Application of Technology

For application of this technology, it is indispensable for the bacteria to be able to grow. First, necessary conditions are listed below.

① Sulfate acidic solution : in case of mixed acid, content of sulfate ion should be dominant. As halogen ions have negative influence on bacteria growth, these inhibitors should be under certain concentration listed below.

② pH range should be 1.3～4.5 (most suitable pH : 2.5).

③ Temperature should be 10～37℃ (most suitable : 30～35℃) : activities under 10℃ are reported, though.

④ Aerobic atmosphere

⑤ Inorganic substrata are coexistent : ferrous (Fe^{2+}) , sulfur (S), thiosulfuric acid ($H_2S_2O_3$) etc.

⑥ Inhibitors should be under certain concentration.

Highly sensitive and low durability	Medium durability	Comparatively high durability
Hg, Ag, Mo, Te, Se, U, CN^-, F^- Specific organism	Sn, As, NO_3^-, $Cl^{-(*2)}$ Low molecular organism	Zn, Ni, Co, Cu, Mn, Al, Cd, Cr

Note) Durability of bacteria might be improved when cultured as inhibitor concentration is increased gradually.

*2 : limit is normally under 1g/L, however, could be improved up to about 10g/L if cultured gradually.

8.3 Possibility of Application

This type of bio-technology could be applied to the following four industrial fields [(1)～(4)] inside Chile.

(1) Treatment of drainage from operating or closed mines processing.

If waste solution is accumulated in evaporation ponds, harmful elements in the solution penetrate into soil from their bottom or sides, unless kept waterproof, resulting in contamination of nearby water system. Just like in Ovalle, if ferrous ions are in solute, they can be oxidized, neutralized and removed as sediments to prevent pollution. This type of application is not seen in Japan since all the Cu mining are now closed.

(2) Treatment of drainage from operating or closed mines

As mine drainage usually contains harmful elements, nearby water systems are often contaminated. If ferrous ions are in solute together with $As^{3+,\ 5+}$ or Cd^{2+}, they can be oxidized, neutralized and removed with use of bacteria activity. This procedure has been realized in Japan at former Yanahara and Matsuo mine etc. successfully.

The process flow is illustrated in Figure 8-1. In the Figure, key application point is indicated as Iron oxidizing with bacteria.

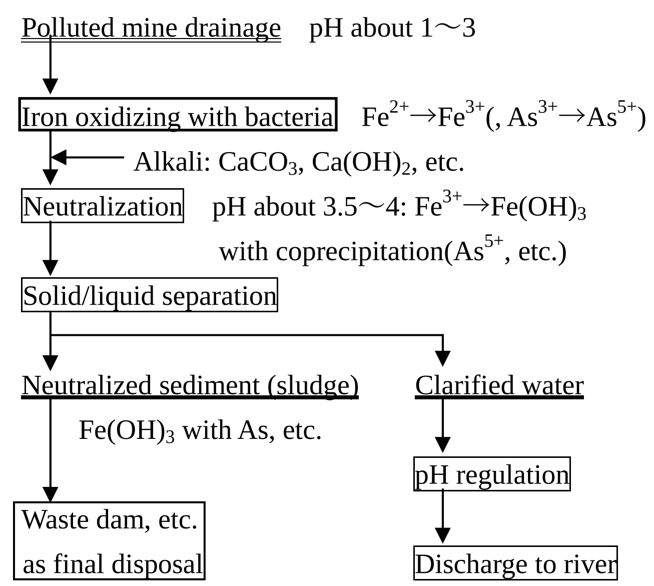

Figure 8-1 An Application of Bio-technology to Treatment of Mine Drainage

(3) Treatment of flue dusts at smelters

Through smelting operation some flue dusts, which contain large quantity of valuable and harmful metals are often stock piled as intermediate refractory material. If the heavy metals dissolve, nearby soil and water are inevitably contaminated. This problem can be handled with use of this technology not only for elimination of contamination but for recovery of valuable metals like Cu.

In Japan, this process is now realized at Kosaka Cu smelter. One example of treatment flow at Cu smelter is illustrated in Figure 8-2. In the Figure, key application point is indicated as [Iron oxidizing with bacteria].

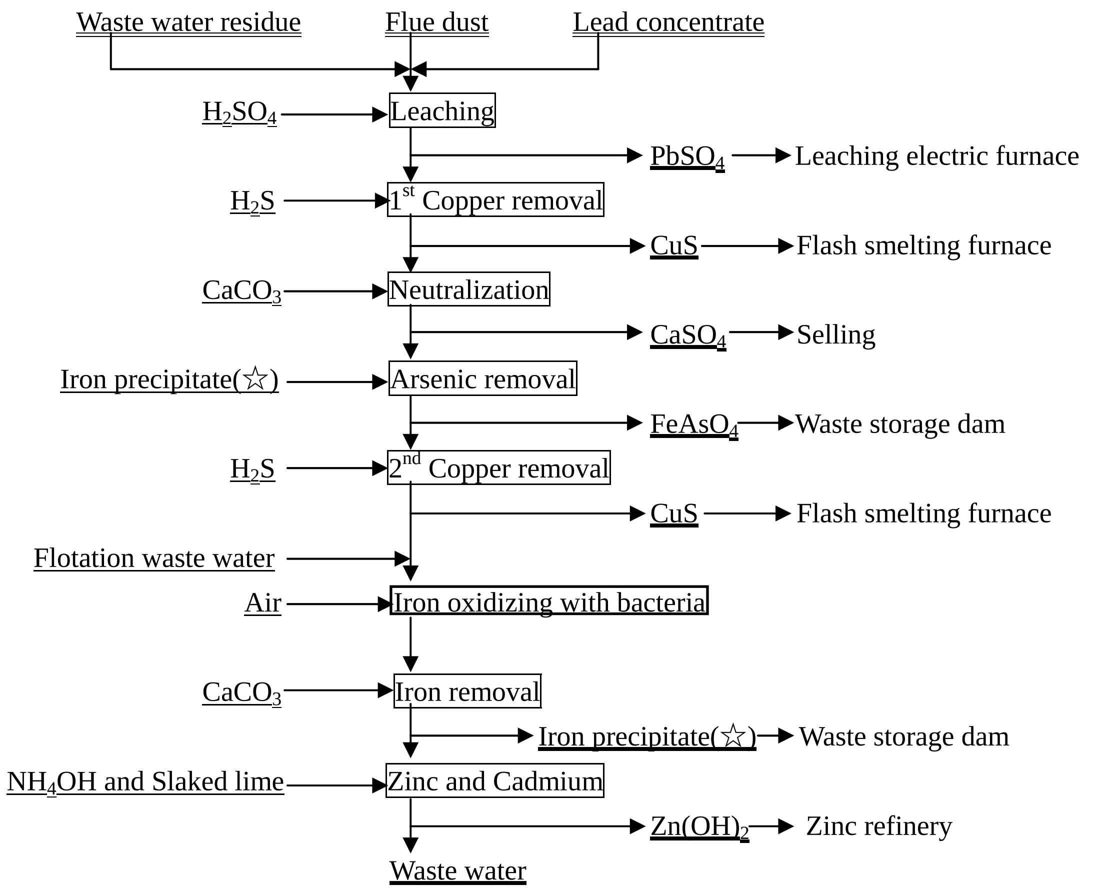

Figure 8-2　An Application of Bio-technology to Cu Smelting Operation (Flue Dust)

(4)　Leaching of secondary Cu sulfide ores with use of bacteria

Acid leaching has been limited to oxide Cu processing only until recently, however, with use of bacteria secondary Cu minerals like chalcocite and covellite became target of this process.

Traditionally from these secondary Cu ores, Cu concentrate is obtained by flotation first, and then electrolytic Cu is finally produced through pyrometallurgical process. This is still a leading process widely employed.

But recently, so-called bacteria leaching method is positively introduced not only for low grade ore or waste rocks, which are economically infeasible with traditional process, but also for average ores, which can be processed by normal flotation and smelting process. After leaching, electrolytic Cu is finally produced through solvent-extraction and electro-winning (SX-EW) method. This series of processing is now employed at almost all mines and is being studied at some mines for future operation because entire operation costs could be much decreased compared to the traditional operation. This unique method will be spread further especially for secondary Cu ores.

Leaching with bacteria is theoretically considered in two ways as follows.

① Indirect leaching mechanism : Ferrous ions are oxidized with bacteria activity to ferric, which chemically react with sulfide minerals to oxidize.

(In case of covellite)

$$4Fe^{2+} + 4H^{+} + O_2 = 4Fe^{3+} + 2H_2O \qquad (1)$$

$$CuS + 2Fe^{3+} = Cu^{2+} + 2Fe^{2+} + S^{0} \qquad (2)$$

Usually, the reaction (1) proceeds so slowly under acidic condition but with the presence of bacteria its velocity could reach five hundred thousand times as fast as the usual.

Ferric (Fe^{3+}) ion acts as an oxidizing agent on CuS, which is oxidized and dissolved to form Cu^{2+}, while ferric ion is reduced to ferrous (Fe^{2+}) and prompts the reaction (1).

In this mechanism ferrous ions are indispensable and naturally available by oxidation of sulfide minerals containing Fe, typically iron pyrite (Fe_2S) following the reaction (3) shown below.

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4 \qquad (3)$$

② Direct leaching mechanism : The bacteria themselves adhere to the surface of sulfide acting as a catalyst to prompt oxidizing reaction as below.

$$CuS + 2O_2 + 2H^{+} = Cu^{2+} + H_2SO_4 \qquad (4)$$

Yet some factors of the reaction are not found out.

This process of bacteria leaching are already practiced in heap/dump leaching for Cu ores, in place leaching for uranium ores and others.

At present bacteria that naturally grow at site are being utilized in most cases. But if any treatment facilities of waste solution containing ferrous ions are available at hand, cultured bacteria could be intentionally employed for leaching of Cu minerals. Typical examples were seen at Kosaka and Tsuchihata mine, now closed, in Japan.

Types of bacteria useful for leaching process are Thiobacillus ferrooxidans and Thiobacillus thiooxidans, Leptospirillum ferrooxidans, Acidiunus brieleyi, Metalloshaera sedula, Sulfolobus acidocaldarius, TH1, TH2, TH3, ALV, BC, Sulfobacillus thermosulfidooxidans, Sulfobacillus thermosulfidooxidans subsp. thermotolerans, Sulfobacillus thermosulfido-oxidans subsp. asporogenes, Thiobacillus prosperus, Thiobacillus cuprinus, Thiobacillus acidophilus.

Primary Cu mineral, chalcopyrite, is hardly leached by acid even with help of bacteria due to slow reaction. Leaching methods for this mineral is now being studied with ammonia, halogens, strong oxidizing agents or pressure leaching etc.

(5) Others 1 : Purification of circulated acid to leaching step

Solvent Extraction and Electro-Winning process is now widely applied to oxide Cu at many mines. A little concern remains in the process that Fe accumulates in circulated acid resulting in decrease of Cu recovery by lowering selectivity of solvent in extracting step as well as in decrease of electrolysis efficiency. It is expected to eliminate accumulated Fe with use of this technology for improvement of operation results. But as further studies are needed, discussion shall be excluded at the moment. No examples are seen in Japan.

Others 2 : Recovery of Au and Ag contained in pyrite or arsenopyrite (FeAsS)

Au and Ag in sulfide minerals are hardly recovered even by leaching with cyanides. But it is possible to increase their recovery rate by pre-treatment with bacteria. Several methods like Biox, BioPro, GeoCoat process are proposed. At the moment these shall be excluded out of discussion.

8.4 Discussion on Possible Application Sites in Chile

Concrete studies are made on possible application of this bio-technology in each industrial field discussed in the previous section, 8.3.

(1) Treatment of waste solution from Cu precipitation method in oxide Cu processing

Discussion is made on ENAMI's processing plants first as well as some small and medium size plants other than ENAMI. As the results, the technology could be possibly applied to the following sites.

① Ovalle plant, ENAMI : The rest of the waste solution beyond capacity of the model plant could be a target.

② Vallenar plant, ENAMI : (solution pH : 2.7, Fe^{2+}9,700mg/L, T-Fe 16,800mg/L, Cu 467mg/L, Cd 0.43mg/L, Pb 1.1mg/L, As 1.9mg/L)

③ Cu recovery plant from precipitation step of Cu smelter dusts (for example : Monte Carmelo plant, where flue dusts from Cu smelter is treated by exchanging precipitation method (solution pH : 2.4, Fe^{2+} 35,400mg/L, T-Fe 36,800mg/L, Cu 906mg/L, Cd 1,410mg/L, Pb 0.7mg/L, As 3,200mg/L)

④ Cu recovery plants from leaching-precipitation step at small scale mines : The following private mines could introduce the method, though their scale are too small.

Name	pH	Fe^{2+}	T-Fe	Cu	Cd	Pb	As	(mg/L)
C.G. plant	0.4	49,000	54,100	239	0.14	1.1	1.8	
L.C plant	3.4	unknown	3,140	173	0.09	0.6	0.16	
S.G plant	3.8	unknown	51,100	274	0.19	1.2	0.71	

In case of above ③ and ④, it is recommended that ENAMI takes a leading position of installation of a centralized treatment plant, now that the technology was transferred through this Study.

Inside ENAMI, M.A. Matta plant is processing only sulfide Cu and out of consideration to apply from the beginning. El Salado plant is processing oxide Cu, however, can not introduce this method while treating Atacamite ($Cu_2Cl(OH)_3$) due to extraordinarily high content of chlorine (39.8g/L) in the solution, far beyond the upper limit (10g/L) for bacteria activity. Nor at Taltal plant, where sea water is utilized in the process that brings chlorine concentration far above the limit.

Inside CODELCO no Cu precipitation method is being employed.

Among the private miners, many mines like Dona Ada, El Indio, Fortuna de Cobre, La Cascada, Lo Aguirre etc. have gradually switched Cu precipitation method to modern SX-EW from the beginning of 1990's. Currently, there are no medium or large scale mines operating this precipitation except very small ones.

(2) Treatment of mine (operating or closed) drainage

On this item following discussions were carried out.

Prerequisite to target mine : located in an area south from Copiapo city in the Ⅲ region, at least occasionally rains, sulfide mineral deposit especially containing iron pyrite(*3), open pit or underground, mine drainage is discharged into nearby river with no treatment. C.A. mine is an example :

	PH	Fe^{2+}	T-Fe	Cu	Cd	Pb	As	(mg/L)
Example ①	1.1	60	60	247	0.06	0.1	0.06	
Example ②	3.9	190	190	548	0.13	0.2	0.24	

*3 Sulfur contained in sulfide minerals is easily oxidized to form sulfuric acid solution. Especially iron pyrite is very likely under existence of oxygen, water and bacteria as in the reaction of (3), described in section 8.3 (4). Also from sulfur produced by the reaction (2) in the same section, is easily dissolved to form sulfuric acid as below, especially with help of bacteria.

$$2S^0 + 2H_2O + 3O_2 = 2H_2SO_4 \qquad (5)$$

This sulfuric acid dissolves harmful heavy metals, which contaminate nearby water systems.

(3) Treatment of flue dust at smelters

Application of bio-technology was studied as follows.

① ENAMI : Ventanas Cu smelter

② CODELCO : Chuquicamata, Caletones (El Teniente), Potrerillos (El Salvador) smelters

③ Private companies : N.A. Cu smelter, D.C. Cu smelter

When Fe content in flue dust is insufficient, addition of Fe^{3+} would be indispensable. This is the case ①, above mentioned. In the case of ② and ③, more study is needed.

In the case of Paipote Cu smelter of ENAMI, flue dusts are not discharged out of the operation and then excluded from the discussion.

(4) Bacteria leaching for secondary Cu minerals

Application was studied as follows.

① Bacteria leaching could be applied to any mines of secondary Cu like chalcocite (Cu_2S) or Covellite (CuS), if leaching and SX-EW process will be programmed for production of electrolytic Cu, not through flotation method (for example, E, Z, and Q.B. mine etc.)

The present situation of Cu production by Chilean large mines is shown in Table 8-2.

8.5 Summary of Possible Application of Bio-Technology in Chile

Supposedly in Chile, “Treatment of mine (operating or closed) drainage” described in 8.4 (2), will be given the first priority of technical discussion. But actually, the situation of water contamination is not clear, though it is supposed to happen in wide area.

Accordingly, along with the field survey of current contamination, application of this technology should be studied in detail on individual site. Some detailed items are listed in the Table 8-1, in which the underlined parts are especially to be noticed.

Finally it is concluded that in Central and South America, application of the technology is possible.

Table 8-1 Treatment of Mine Drainage from Operating or Abandoned Mines with Bio-technology (Scheme)

(1) Environmental survey

1) Present situation survey

① Survey of pollution source: Grasping quantity and quality of drainage from mines, and quantity and quality of water and bottom sediment of relative rivers by preliminary survey to confirm their concentration and quantity of load. Then, defining pollution source. At the same time, grasping pH, acid with sulfuric acid, concentration of Fe^{2+}, with or without iron oxidizing bacteria and concentration of inhibitors to the bacteria to confirm chance to apply to the treatment of mine drainage by using bio-technology with iron oxidizing bacteria.

② Survey of pollution situation: Mapping of pollution situation to define pollution degree in contrast to the standard. Then, drawing contour line on pollution to confirm degree and range of pollution. Moreover, Grasping order of priority of measures necessary to every pollution source according to largeness of pollution impact.

③ Survey of pollution mechanism: Clarifying pollution route and reaction from pollution source

④ Survey of suffering situation: Grasping suffering situation of human body of every industry

2) Monitoring

① Formulation of monitoring plan: Fixing monitoring items and points necessary for future continued monitoring according to result of above-mentioned present situation survey.

② Monitoring survey: Sampling and analyzing on water quality, and measuring quantity of water at regular intervals to accumulate data. Revising pollution source, pollution situation and pollution mechanism with the result, and grasping change with the passage of time.

③ Formulation of water quality analysis model: Constructing model to analyze quality of water concerning pollution mechanism.

④ Survey of water quality simulation: Grasping degree of mitigation for pollution at every polluted point according to method and degree of measures for mine pollution prevention at pollution sources with simulation by above-mentioned model of water quality analysis.

(2) Study on measures for mine drainage

1) Study on technology of measures for mine pollution: Grasping overall technology of the measures for mine pollution, that is, pollution source measures, mine drainage treatment, etc..

2) Study on technology of measures for mine drainage: Narrowing down technology of measures for polluted mine drainage necessary to site where mine pollution occurs in Chile, from above-mentioned technologies.

3) Formulation of measures process: Studying process of measures of mine pollution prevention for every pollution source.

⇒ Herein, the bio-technology mentioned in this report may be applicable.

Construction of process with bio-technology by using iron oxidizing bacteria: Peculiar technique has to be necessary.

4) Test of measures process: Confirming the process and grasping optimum treatment condition.

5) Design of facilities: First, conducting conceptional design for pollution source with larger impact, and conducting analysis economics and financial affaires. Succeedingly, conducting detail design.

(3) Practice of measures for mine drainage

1) Construction of model plant (pilot plant): Small-scale model plant will be constructed based on above-mentioned design to restudy optimum condition and confirm fulfillment of criteria for applied technology.

2) Construction of full-scale plant

3) Operation of the plant: Conducting mine pollution prevention.

Table 8-2 Major Copper Mine in Chile

No.	Name of Mine	Ownership	Processing Ore*[5] Sulfide	Oxide	Location : Region	Production in 2000 Cu ×10^3t/year
1	Escondida	BHP 57.5+RTZ 30+JECO 10 *[1]+IFC 2.5%	○	○	II	917
2	Chuquicamata	CODELCO	○	○	II	630
3	Collahuasi	Falconbridge 44+AAC(Anglo American plc.) 44+Japan Conso. 12%*[2]	○	○	I	436
4	El Teniente	CODELCO	○	○*[6]	VI	356
5	Los Pelambres	Antofagasuta Minerales plc. (Luksik) 50.55 +Anaconda Chile 9.45 +Japan Conso. 40%*[3]	○		IV	310
6	Andina	CODELCO	○		V	258
7	Candelaria	Phelps Dodge 80+Sumitomo group 20%*[4]	○		III	204
8	Radomiro Tomic	CODELCO		○	II	191
9	El Abra	Phelps Dodge 51+CODELCO 49%		○	II	191
10	Los Bronces	Exxon Mobil (Disputada de Las Condes)	○	○	M*[7]	170
11	Zaldivar	Placer Dome	○	○	II	148
12	Cerro Colorado	Billiton (Rio Algom)		○	I	115
13	Mantos Blancos	AAC	○	○	II	102
14	Salvador	CODELCO	○	○	III	81
15	Quebrada Blanca	Aur 76.5+Pudahuel 13.5+ENAMI 10%	○	○	I	73
16	El Soldado	Exxon Mobil (Disputada de Las Condes)	○	○	V	68
17	Manto Verde	AAC		○	III	54
18	Michilla (Lince)	Antofagasta (Luksik)	○	○	II	53
19	Lomas Bayas	Bolden: Noranda+Falconbridge		○	II	51
20	Andacollo	Aur 63+Pacifico 27+ENAMI 10%		○	IV	21
21	El Indio	Barrick	○		IV	14
22	Ivan Zar	Milpo (Peru)		○	II	13
23	Minera Valle Central	Valle Central	○		VI	12
24	Punta del Cobre	Punta del Cobre	○		III	10
25	Las Luces	Las Luces	○		II	10
26	La Cascada	Pudahuel		○	I	5
27	Lo Aguirre	Pudahuel	○		M*[7]	5

Note *[1]: Mitsubisi-shoji 6+Mitubishi-material 2+Nikko-kinzoku 2%

*[2]: Mitsui-bussan 6.9+Nikko-kinzoku 3.6+Mitsui-kinzoku 1.5%

*[3]: Nikko-kinzoku 15+Mitsubishi-material 10+Marubeni 8.75+Mitubishi-shoji 5+Mitsui- bussan 1.25%

*[4]: Sumitomo-kinzokukouzan 15+Sumitomo-shoji 5%

*[5]: Sulfide copper ore (process: flotation, product: copper concentrate),
Oxide copper ore (process: SX-EW, product: electrolytic copper[cathode copper])

*[6]: This SX-EW is brought about by treatment of acid drainage water from mine.

*[7]: Metropolitan

９. Conclusion

9. Conclusion

The Study project that has searched any economical and environmental improvements in the operation of Ovalle plant, ENAMI, for thirty nine months since Oct., 1999, was now brought to a conclusion. Throughout the Study period, surrounding economic conditions have been unstable and social crises like deflation, monetary crisis and unrest of employment were seriously likely to happen worldwide.

Also in the copper producing industry, mining activity that was ever seen in the past, for example, the first half of 1990's has never encountered throughout the period due to the depressed price of this metal at the market. In the Republic of Chile, holding the first place in the industry, small and medium miners have suffered the lower price and were forced to reduce their production, while the large mining companies are still operating favorably. The technical counterpart of the project, ENAMI, promoting small and medium size miners on the one side, are now also suffers a shortage of ores on the other, because it entirely depends upon outside suppliers for crude materials.

Although there might be different opinions from the social standpoint of ENAMI, it is desirable for ENAMI to program an independent operation, for example, by operating its own mines or by cooperating with a third party for full supply of crude ores. Should improvement of productivity be reflected in the profit, management would be much encouraged itself.

Increase in production could contribute most to profit increase, however, in case of Ovalle profit will be raised by accumulation of minor technical works. For that purpose, accumulation of basic data and experimental results is indispensable.

Installation of the Model Plant was completed successfully in good cooperation with the counterpart throughout basic tests, plant design, installation works and demonstration test operation.

Waste solution from the previous leaching section was purified through treatment at the model plant as expected. Also actual treatment capacity of the plant exceeded $100m^3$ per day, originally designed. Including technology transfer the project has proved very successful in the technical aspects.

Design of a so-called “full scale plant”, in which the model plant shall be replaced by an industrial one to meet full volume of the waste solution from the leaching step, was conducted based upon the maximum treatment capacity at the leaching operation with 14,000ton of crude ore per month. Total volume of the waste solution will reach $600m^3$ a day. If this plant is realized, the existing model plant shall be operated as a supplement and the investment for the new installation would cost approximately US$ 2.12 million. Based upon this full scale operation and full volume of waste solution treatment, economic analyses were carried out as case study on different levels of the market price of copper. However, usual Cash Flow analysis, detailed in the Chap. 6, indicated that no feasible results would be brought in each case. This is a weak point in putting some environmental countermeasures in practice, because no profits are unlikely to be brought in many cases.

For justification of environmental projects like Ovalle, it is important to consider any impacts, which could influence on nearby communities. In this Project, possible economic effects on the neighboring farmlands, meadows, mines etc. were quantitatively analyzed. They are :

① The value of land, which has remarkably decreased due to contamination, shall be re-established through restoration works.

② Economic effects on the ore supplying miners shall be included, when Ovalle plant is fully operated.

③ Saving in water consumption inside entire community shall be economically analyzed.

As the results of these analyses, it was found that the full scale (14,000t/month) operation could be feasible if the copper price is above US ¢ 68/lb-$_{Cu}$, when the above factors are included.

Now that the full scale operation at Ovalle could be feasible, the installation of full volume solution treatment plant is highly recommended. Once this is fulfilled, no contamination shall be discharged out of the plant, copper recovery will be improved by circulating the waste solution for reuse and ideal operation would be established at Ovalle both economically and environmentally.

However, current situation surrounding the copper mining industry is too severe to allow ENAMI a large amount investment at once. It would be appropriate to leave the final judgement to ENAMI management on how and when the investment should be realized. For the time being, actual operation will last at around 6,000 ton per month but if the situation turned favorable, full scale operation (14,000ton/month) as well as installation of full solution treatment plant should be promoted.

While the current low level operation continues, another discussions are needed on how environmental requirements shall be met with use of the existing model plant alone. On this point, the results of discussion made between the both parties are reported in the Chap. 7. of this Report.

Environmental countermeasure realized at Ovalle was further discussed through data collection and field survey to apply to other copper processing plants in Chile. But unfortunately suitable plant is not found yet because the operation of copper precipitation after leaching is declining these days replaced by unique process, SX-EW. Accordingly, application of this bio-technology was studied widely on entire mining industry and summarized in the Chap. 8 of this report, which has not yet completed, though. It is expected ENAMI or any institute would promote the ideas to make further progress in future.

Although consciousness against pollution is gradually raised recently, it is not satisfactorily enough. At Ovalle plant, pollution shall be prevented from now on, needless to say, also water and soil contamination brought in the past should be restored positively. For consciousness raising against pollution as well as for presentation of the study results on this project, environment related seminar was held twice in cooperation with the counterpart, ENAMI. One was held in the city of La Serena in March, 2002 and another in Santiago in October, 2002 respectively. Both seemed to have attracted the attendance, which counted more than fifty in each case.

Completing the entire Study, the Japanese Study Team would like to express thanks to ENAMI and related institute for offering valuable data or information and also to the counterparts concerned for cooperative works. Finally, it is desired that Ovalle plant would be literally the model plant of copper ore processing in Chile both in technical and environmental standpoints.