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# HEAT RECOVERING THROUGH ACIDIFICATION: AN ECONOMIC ANALYSIS

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## ABSTRACT

The temperature of flashed brines at Cerro Prieto Geothermal Field suggests a heat recovering study. However, scale formation in equipment, due to supersaturation, becomes one of the most important restrictions to develop a heat transfer process.

Previous reports of experiments carried out with this brine showed that it is possible to reduce the scale deposition through acidification.

This paper presents a feasibility study to recover heat from waste brines.

## INTRODUCTION

At Cerro Prieto Geothermal Field, waste brines have an average temperature of 360 F. This value suggests that heat can be recovered through a Binary Power Cycle utilization. However, these brines have an average salinity of 30,000 ppm and a silica content of 1,000 ppm. So, a high quantity of solids precipitates when these brines are cooled. The formed scales reduce the overall heat transfer coefficient. On the other hand, erosion car occur from the brines running through the equipment at high velocities.

Some experiments were carried out in order to inhibite silica deposition. When 30 ppm of hydrochloric acid were added there was no polymerization in a period of 35 minutes. This control of scaling seems to be a solution to recover heat from the Cerro Prieto waste brines.

The goal of this paper is to develop a feasibility study to recover heat from waste water in order to improve a research project.

## SILICA POLYMERIZATION

The silica polimerization velocity is a strong function of supersaturation, pH and salinity (Harvey and others, 1976).

The supersaturation ratio is defined as the relation of current to equilibrium concentration. The induction time of nucleation increases when this ratio is about 2.

It has benn pointed our (Iler, 1989) that polymerization of silica involves an ionic mechanism. When pH is above 2, the rate of polymerization is proportional to the concentration of hydroxil ions.

Previous experiments (Hill and others, 1977) have demostrated that decreasing one pH unit leads to lower nucleation by a factor of 10. For instance; it has been shown that a brine at $pH < 4.6$ produced 1/10 of the amount of solids produced in brine at $pH = 5.8$.

In the Table 1 are shown comparative scaling rates calculated (Weres and others, 1982) for separated water from different Cerro Prieto wells. The first values correspond -- to unmodified brines and the second to $pH <3$ brines.

TABLA 1.- SCALING VELOCITY GROWTH (mm/year)

| WELL | unmodified | pH <3 |
|---|---|---|
| a | 1.215 | 0.00043 |
| b | 0.354 | 0.00012 |
| c | 1.872 | 0.00083 |
| d | 0.402 | 0.00016 |
| e | 0.263 | 0.00017 |

The above results indicate that scaling is controlled at low pH values. In addition , the values show that scale acumulation becomes negligible.

## BINARY CYCLE CALCULATION

The working fluid selection for Cerro Prieto geothermal brines was made according to temperature ranges (Ingvarsson and Turner, 1978). Isobutane was selected.

Figure 1 shows the flow diagram for the geothermal power plant using a supercritical rankine cycle with isobutane as the secondary fluid. The Cerro Prieto waste brines are the heat source.

## DESIGN CONSIDERATIONS

### HOT FLUID

Waste brines were selected as the hot fluid, which has a 360 F, and 1000 ppm $SiO_2$ both of them are average values. These brines are obtained as separated water from the Webre bottom Outlet Cyclon. Previous acidification will be done in order to avoid scaling in the equipment.

### ACID

Brines were acidified with hydrochloric acid. The acid addition will not affect the content of heat in the brine. The quantity of acid used was 40 ppm.

## ECONOMIC ANALYSIS

### METHODOLOGY

The model used in this study was the Net Present Value (NPV) (Ziman and Rosenberg, 1982), defined as:

$$NPV = \sum_{t=1}^{N} (Rt-Ct)/(1+d)^t$$

WHERE:

| | |
|---|---|
| Rt: | Gross Revenue in year t |
| Ct: | Cost of the project in year t |
| N : | Lifetime of project (Construction and operation) |
| d : | Discount rate |

A baseline case for this study is analyzed using the same definition with a Zero or Positive Value for NPV in order to approve a project, or reject it for negative values considering "d" as the minimum atractive return rate.

Therefore, the NPV was set equal to Zero in order to calculate the internal rate of return and the break-even price for the minimum atractive return rate for the same baseline case.

The last method also is used in order to evaluate the impacts of the internal rate of return upon capital cost plant and Operation and Maintenance costs. In these - cases, the limit for the internal rate - of return is the discount rate.

## PLANT CAPITAL COST

The costs of the main equipment were estimated according with the information reported by Nelson (1986) and related to the Heber Binary Project. These costs were taken in unitary basis and actualized to 1989 dollars using the Chemical Engineering Plant Cost (CE) and Marshall and Swift Equipment (M&S) indexes (Table 2).

The main equipment costs were used as a reference in the capital cost plant calculations. The capital cost distribution shown by Demuth (1983), was adapted for the Mexican case for piping, construction materials instrumentation, with emphasis in labor and indirect cost. The final results are reported in Table 3.

## ELECTRICAL POWER GENERATION

The gross output from the electricity generator (10 MW) was calculated from a direct thermodynamical analysis using an efficiency of 80% for the turbine-generator coupling. The plant load was estimated calculating the energy consumptions for pumping and cooling, including an estimate value for turbine-generator services. As a result, a net output of 7.828 was obtained (Table 4).

The annual electrical power generated (AEPG) was estimated with a plant factor of 90%:

AEPG= (7828 kw) (8760 hr/yr) (0.90)
= 61,652,880 kwh/year

The baseline energy price was considered as 0.04 $/kwh, and the annual gross revenue was 2,466,118 dollars per year.

## OPERATION AND MAINTENANCE COST

O&M cost were evaluated using an unitary value of 60 $/net kw/yr. This value agrees with the values reported in the literature (Bloomquist, 1985, Karlson, 1984) for binary cycles. As a result, an annual cost of 470,352 $/year was calculated.

## BASELINE CASE PARAMETERS

An economic analysis for the baseline case was performed considering the following parameters.

| | |
|---|---|
| Generator gross output (kw) | 10,000 |
| Plant net output (kw) | 7,828 |
| Construction and start up time (yr) | 1 |
| Project lifetime (years) | 30 |
| Capital cost plant (dlls 1989) | 9,018,219 |
| O&M cost ($/year) | 470,352 |
| Electrical power price ($/kwh) | .04 |
| Gross revenue ($/year) | 2,466,115 |
| Minimum attractive rate of return | .15 |

In acoordance with the objectives of this study, inflation, energy price escalation, and taxes were not considered.

A direct geothermal fluid cost was not asigned because it is actually considered as a waste fluid; however, the acidification cost is accounted on a higher equipment cost (heat exchangers) due to corrosion effects. The direct cost of the acid does not have a representative impact.

The economic evaluation of the baseline case is presented in FIGURES 2, 3 and 4. The positive NPV suggests an acceptable profit. For the selected parameters, the internal rate of return is 18% which is within the range for geothermal projects. If the minimum atractive rate of return is fixed at 15% the electrical power break-even price would be 0.033 $/kwh (see figure 5)

The relationship between the electrical power price and the internal rate of return is shown in FIGURE 5. If we think on a discount rate basis, a 0.03 $/kwh value would be atractive.

FIGURE 6 shows the impact of plant capital cost on the internal rate of return. The higher value for a discount rate of 10% is 1699 dollars per installed kw, comparing with the values reported for binary plants (Bloomquist, 1985).

Finally, the O&M cost versus the internal rate of return are shown in FIGURE 7. According with the mentioned criterium in the last paragraph, a maximum value of 180 dollars/net kw/year would be allowed.

## CONCLUSIONS

According to the economic analysis and considering that the limit value for the minimum atractive return rate could be 13% as a discount rate, the profit of the project alows:

* A minimum electrical power price of .03 $/kwh, or
* A maximum O&M factor of 140 $/Wet kw/year, or
* A maximum plant capital cost of 13 million of dollars

As a result, it is atractive to develop a research project for recovering heat from waste brines.

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### TABLE 2

### MAIN EQUIPMENT COSTS

| | |
|---|---|
| BRINE PUMPS. | |
| 2 Units 1250 gpm,120 ft,50HP | $ 17090 |
| HEAT EXCHANGERS | |
| 2 units, 25,000sqft/shell | $1306005 |
| TURBINE GENERATOR | |
| Double axial 3600rpm 10MW | $ 936149 |
| CONDENSER | |
| 2 units cross flow 30000sqft per shell | $ 801564 |
| CONDENSATE PUMPS | |
| 2 units 2200 gpm, 500ft,200HP | $ 63291 |
| BOOSTER PUMPS | |
| 2 units 2200gpm,1100ft,1750HP | $ 158695 |
| COOLING WATER PUMPS | |
| 2 units, 10000 gpm, 100ft,300HP | $ 121522 |
| COOLING TOWER | |
| Induced shaft counter-current | $ 459863 |

(1989 dollars)

### TABLE 3

### PLANT COSTS (1989 dollars)

| | |
|---|---|
| WORKING FLUID | |
| Heat exchangers | $ 1306005 |
| Condensate pumps | 63291 |
| Booster pumps | 158695 |
| Piping, materials | 802196 |
| Labor | 151271 |
| TURBINE | |
| Turbine-generator | 936149 |
| Piping,materials | 601810 |
| Labor | 88268 |
| HEAT REJECTION | |
| Condenser | 801564 |
| Cooling tower | 459863 |
| Pumps | 121522 |
| Piping, valves,mats. | 163770 |
| Water treatment | 181968 |
| Labor | 72059 |
| GEOTHERMAL FLUID | |
| Pumps | 17090 |
| Piping, mats. | 25500 |
| Labor | 8430 |
| MISCELLANEOUS | |
| Inst. Control, fire syst. | 898012 |
| Labor | 364731 |
| INDIRECT | |
| General administration, Eng, constr. management | $ 1796025 |
| TOTAL | $ 9018219 |

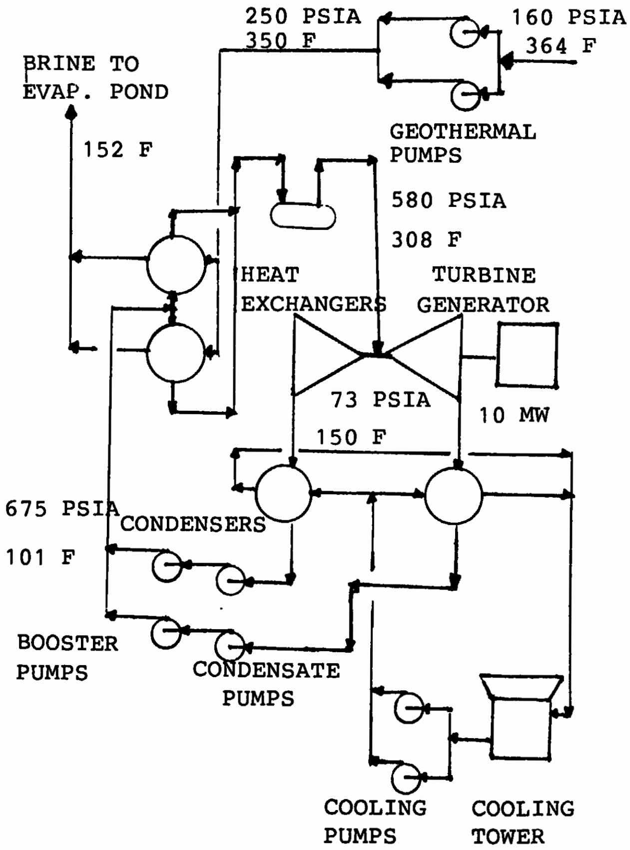
### TABLE 4

### ELECTRICAL POWER GENERATION KW

| | |
|---|---|
| Gross power generated | 10,000 |
| Plant power load : | |
| Brine pump | 67 |
| Condensate pumps | 248 |
| Booster pumps | 1,108 |
| Cooling water pumps | 429 |
| Cooling tower fans | 120 |
| System | 200 |
| NET OUTPUT | 7,828 |

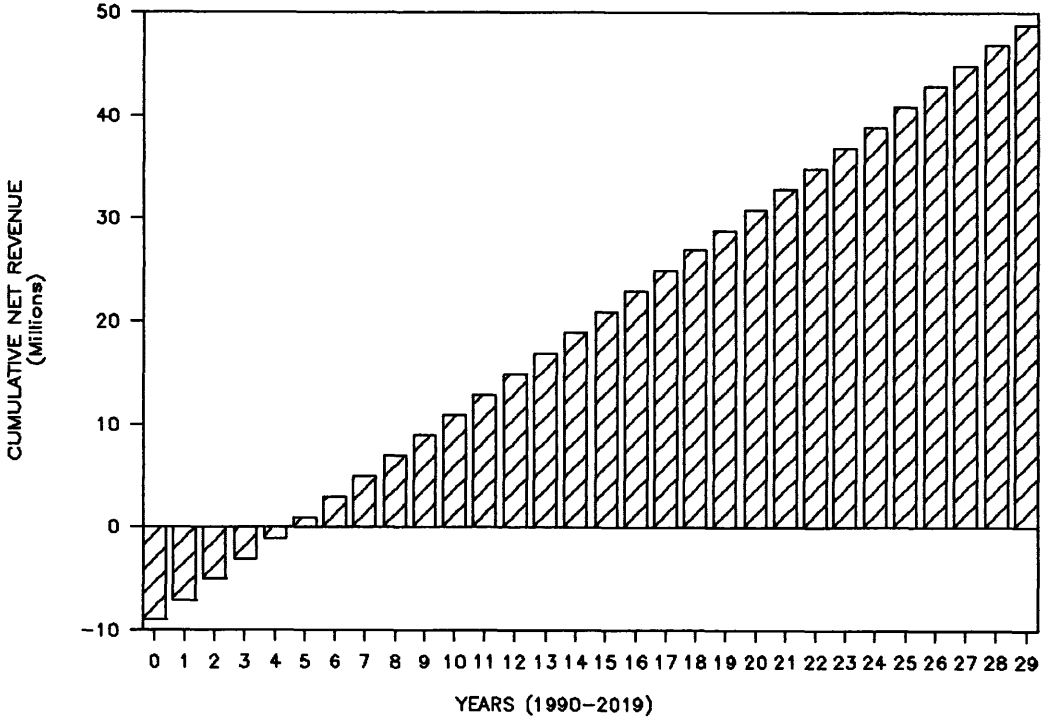
FIGURE 1

PROCESS DIAGRAM



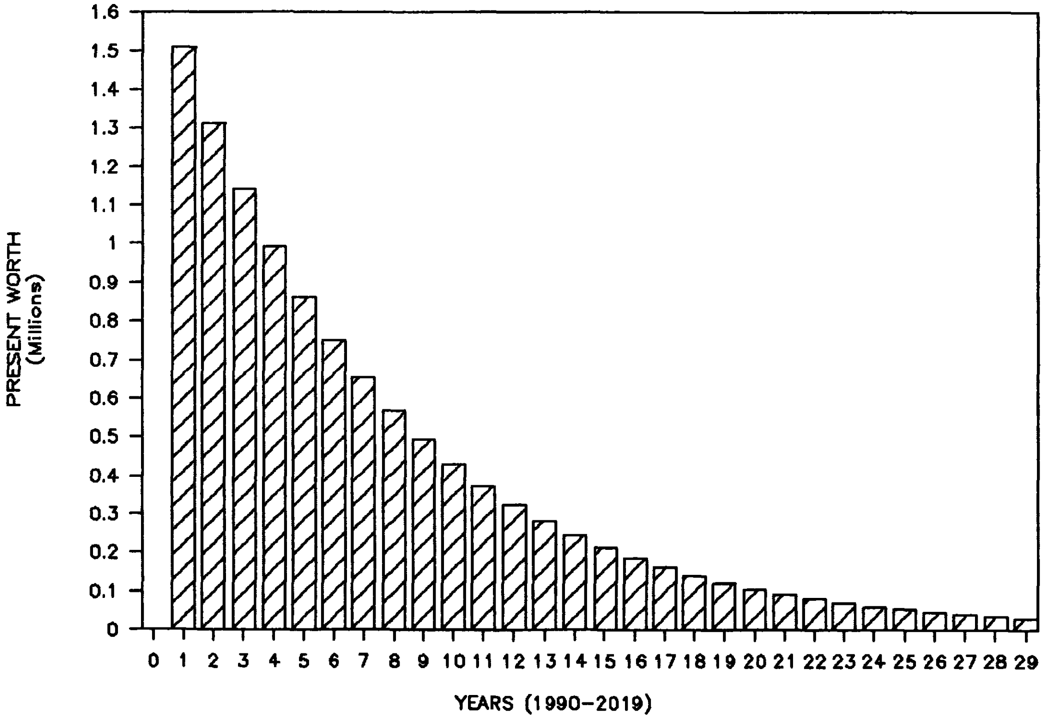
BASELINE CASE ECONOMICAL ANALYSIS

FIGURE 2



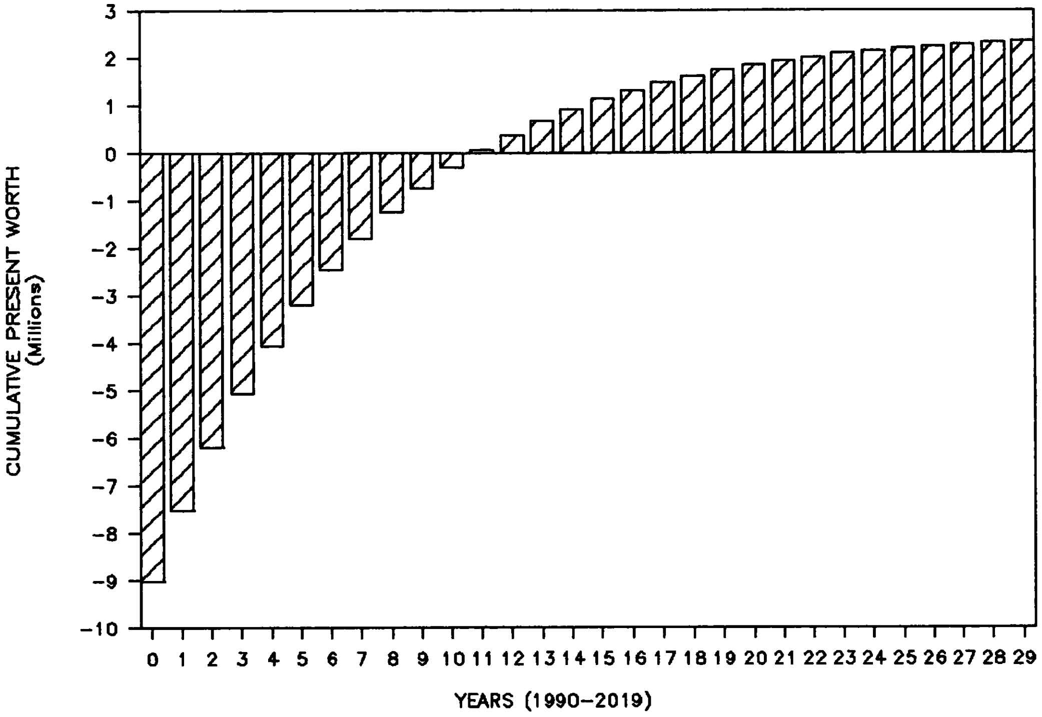
BASELINE CASE ECONOMICAL ANALYSIS

FIGURE 3



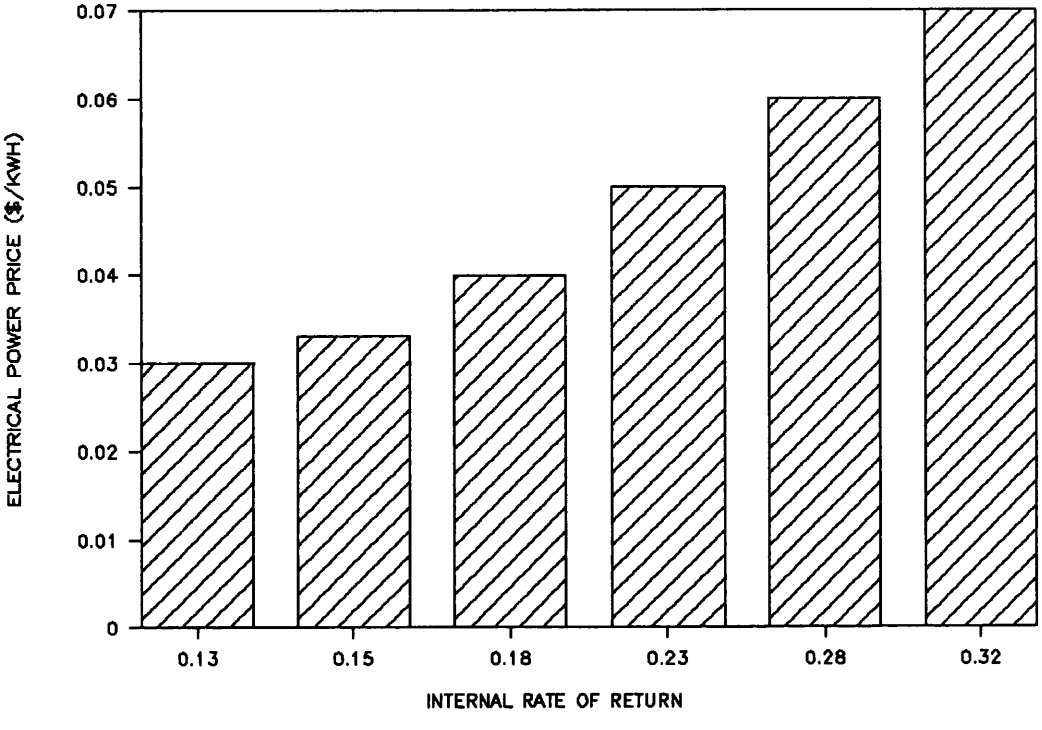
## BASELINE CASE ECONOMICAL ANALYSIS

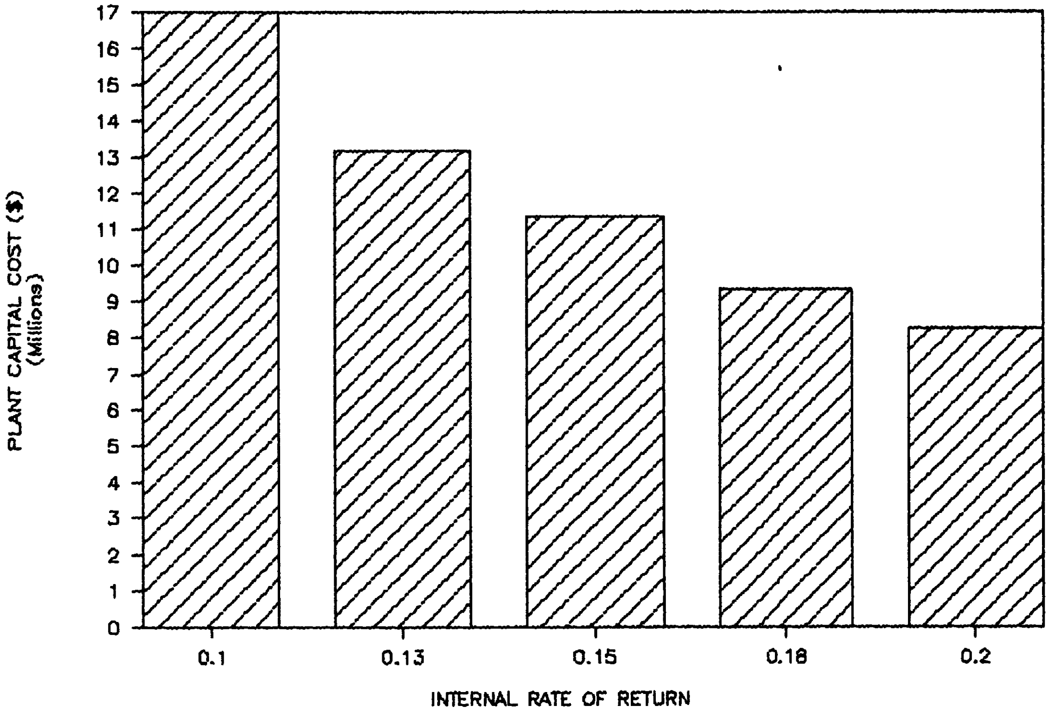
FIGURE 4



## ELECTRICAL POWER PRICE VS IRR

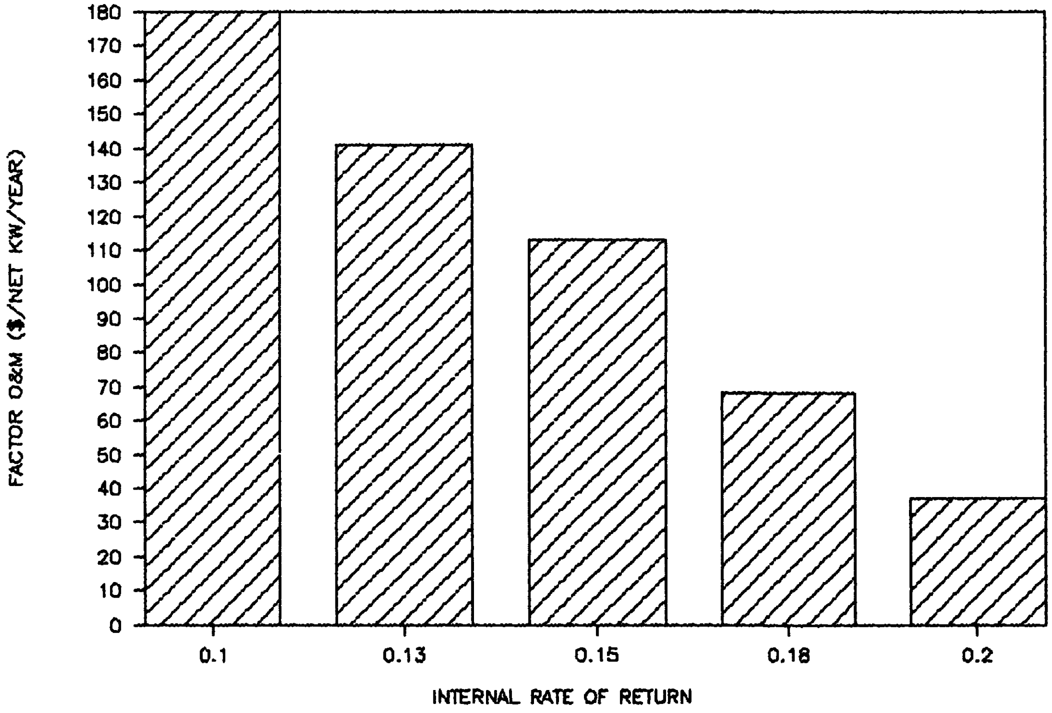
FIGURE 5





PLANT CAPITAL COST VS IRR

FIGURE 6



O&M COST VS IRR

FIGURE 7