

**VERMIR SF.**

Ráðgefandi verkfræðingar  
Reykjavík

PRICE ESTIMATE  
FOR GEOTHERMAL STEAM  
SUPPLIED TO THE DIATOMITE FACTORY AT MÝVATN

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RESEARCH ENGINEERS AND GEOPHYSICISTS

P.O. BOX 268  
REYKJAVIK  
ICELAND

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The State Electricity Authority  
Reykjavik - Iceland

July 1966

(0) SUMMARY

In the following report previous estimates of steam prices to the Diatomite factory at lake Mývatn have been revised with view on the new and revised figures given by Kisiliðjan h/f, in July 1965, for the heat requirements of the plant, and its production forecast for the first 20 years of operation. These data are found in section (1) of the report.

Description of the proposed supply system for geothermal steam is given in section (2), and it is concluded that it would be more practical to use low-pressure steam for heating the mud before filtering than to use high-temperature water under pressure.

Estimates of the capital costs and the operating costs of the steam supply system are given in section (3). An interest rate of 7% per annum is used in all calculations and depreciation of the steam producing plant and supply system is based on 10 years productive life for the boreholes, and 20 years for other equipment. In the annual operating costs royalty on the use of the steamfield, 0.3 Mkr/year, is allowed for as well as a reserve fund contribution of 0.5 Mkr/year. The purpose of the latter provision is to enable the steam producing agency to meet major unforeseen emergencies, such as a sudden failure of a borehole or similar misfortunes.

The costprice of the steam is computed in section (4). On basis thereof two different types of tariffs are proposed, i.e.

Tariff (1): Fixed annual charge of 1.0 Mkr/year plus 16 kr/ton of steam used.

Tariff (2): Fixed unit price for the steam 0.52 U.S.\$/ton=22.36 Kr/ton of steam used.  
(Rate of exchange 1 U.S.\$= 43 kr.)

Tariff (2) leads to lower overall steam costs for the plant during the first years of operation, and is therefore more attractive to the plant than tariff (1), at the same time the steam producing agency, however, runs greater risks if tariff (2) adopted. Table (5) gives detailed comparison between the two tariffs.

Tables nos. (3), (4), (6) and (7) show various calculations made for the propose of illustrating the effects of the tariffs on the finances of the steam supply system. They show that the prices proposed are as low as can be considered compatible with reasonable financial outcome.

A comparison is made in section (7) between the costs of using geothermal steam on one hand and fuel oil in on the other for heating and drying the diatomite. The conclusions is that the use of geothermal steam results in a saving of the order of 8.75 \$/ton of finised diatomite as compared with heating with oil.

(1) INTRODUCTION

In a meeting held in the office of Mr. Jakob Gíslason, Director General of the state Electricity Authority, on 5 July 1966, the representatives of Kísiliðjan h/f presented the following revised and final data relating to heat requirements for processing in the diatomite plant at lake Mývatn:

## (1.1) Heat requirements:

Capacity of plant, diatomite tons/year	12,000	24,000
75 psig steam for driers, tons/hr.	10	20
Steam or superheated water for mud heating, $10^6$ kcal/hr.	1.15	2.30

## (1.2) Production Forecast:

Year	Tons/year diatomite
1968	6.000
69	9.000
70	12.000
71	14.000
72	18.000
73	20.000
74	24.000
75	28.000
76	30.000
77	30.000
78	30.000
79	30.000
80	30.000
81	30.000
82	30.000
83	30.000
84	30.000
85	30.000
86	30.000
1987	30.000

The representatives of Kísiliðjan asked for a firm quotation on the delivery of steam and for hot water for a period of 20 years, i.e. 1968-1987 incl. They further expressed the wish that the tariffs were made in such a manner that the charges for the heat energy during the first years of plant operation were as moderate as possible.

The above figures for the heat requirements are almost twice as high as those quoted in September 1965, and the production forecast has also been altered to some degree since that time.

It was therefore, agreed that Vermir s/f should revise their estimate of November 1965 of the heat prices.

The following report describes the premises used, the calculations and the conclusions.

(2) DESCRIPTION OF THE PLANT

(2.1) Construction program

The diatomite plant will initially have machinery installed for an output of 12,000 tons diatomite per year, and be ready for operation in the summer 1967.

Extension to a capacity of 24,000 tons/year will be ready for operation in 1971.

The steam supply will then have to be able to deliver the full requirements of a 12,000 tons/year plant in 1967 and 24,000 tons/year plant in 1971.

(2.2) Sources of heat

Presently there are two borholes at the site and the third one will be drilled in the summer of 1966. The present yield of the bores is:

Borehole No.		I	II
Wellhead pressure at maximum output	psig	60	92
Maximum steamflow	t/h	10	15.5
" water flow	"	58	86
Temperature of water at well head	°C	152	166

The borhole Nr.II and No.III will supply steam with a pressure of 75 psig at the diatomite plant.

As regards heating of the mud for filtering three possibilities have been studied:

- (2.21) Use of high-temperature water of say 155°C separated from the primary steam at borholes Nos.II and III, as heating medium.
- (2.22) Flashing the high-temperature water at say 130°C and using the steam produced for heating.
- (2.23) Using steam from borhole No.I for heating of the mud. The steam could be delivered with a temperature of over 130°C at the plant.

Analysis shows that the last alternative is most economical and would give highest operational safety. The quantity of steam required for heating the mud amounts to 2.1 and 4.2 tons/hr. for 12,000 respectively 24,000 tons/year diatomite.

(2.3) Arrangements of the steam supply

A 250 mm (10") dia. pipeline will be built in 1966-67 for transmission of the 75 psig steam for the driers. This pipeline has sufficient capacity for the driers of a 24,000 tons plant.

During the first years of operation, when plant capacity is 12,000 tons/year, steam for mud heating can be tapped from this pipeline.

However, when the plant has been fully extended another pipeline may be required for additional steam from borhole No.I for heating of the mud. This pipeline would have to be built in 1970.



TABLE (1) ANNUAL STEAM REQUIREMENTS

Year	Hourly Demand		Annual Steam Consumption		
	Drying Tons/hr	Heating Tons/hr	Drying $10^3$ Tons/yr	Heating $10^3$ Tons/yr	Total $10^3$ Tons/yr
1968	10	2.1	35.0	7.4	42.4
69	10	2.1	52.5	11.2	63.7
70	10	2.1	70.0	14.7	84.7
71	20	4.2	81.6	17.2	98.8
72	20	4.2	105.0	22.1	127.1
73	20	4.2	116.8	24.5	141.3
74	20	4.2	140.0	29.4	169.4
75	20	4.2	163.4	34.3	197.7
76	20	4.2	175.0	36.8	211.8
77	20	4.2	175.0	36.8	211.8
78	20	4.2	175.0	36.8	211.8
79	20	4.2	175.0	36.8	211.8
1980	20	4.2	175.0	36.8	211.8
81	20	4.2	175.0	36.8	211.8
82	20	4.2	175.0	36.8	211.8
83	20	4.2	175.0	36.8	211.8
84	20	4.2	175.0	36.8	211.8
85	20	4.2	175.0	36.8	211.8
86	20	4.2	175.0	36.8	211.8
87	20	4.2	175.0	36.8	211.8
			2,864.3	602.4	3,466.7

(3) COST ESTIMATES FOR STEAM SUPPLY SYSTEM

(3.1)	<u>Summary Estimate of Capital Costs</u>	Mkr.	
(3.11)	Steam borholes:	7.50	
(3.12)	Steam supply line for 75 psig steam, incl. separators, controls, fittings, and foundations	2.60	
(3.13)	Steam supply line for low pressure steam (mud heating)	1.50	
(3.14)	Shed, electrical transmission line, fences and miscellaneous.	0.90	
(3.15)	Contingencies	<u>0.70</u>	
	<u>Total Capital Costs</u>	<u>Mkr. 13.20</u>	
(3.2)	<u>Operating Costs Estimate</u>		
(3.21)	Royalty and capital costs	Mkr.	Mkr.
(3.221)	Royalty on steamfield	0.30	
(3.212)	Interest and depreciation (sinking fund)		
	Boreholes, 7% p.a, 10 years life		
	14. 22% of Mkr. 7.5	1.07	
	Other installations, 7% p.a, 20 years		
	9.44% of Mkr. 5.7	<u>0.54</u>	1.91
(3.22)	Cash outlays		
(3.221)	Servicing and maintenance of steam boreholes	0.14	
(3.222)	Maintenance on other installations	0.11	
(3.223)	Wages	0.30	
(3.224)	Administration, insurance and general costs	0.25	
(3.225)	Laboratory services, prospecting and supervision of steam field	<u>0.20</u>	1.00
(3.23)	Reserve fund contribution	<u>0.50</u>	
	<u>TOTAL ANNUAL COSTS</u>		<u>Mkr. 3.41</u>

(4) DETERMINATION OF THE STEAM COST-PRICE

In order to find the average cost-price of the steam the following premises are used:

- (4.1) The same price is charged for each ton of steam delivered to the plant, whether the steam is used for drying or mud heating (i.e. price independent of the steam pressure).
- (4.2) After the end of the first 20 years of plant operation, i.e. at the end of the year 1987, the sum of the annual operating costs of the steam supply system placed at compound interest, shall be equal to the sum of the annual charges for steam also placed on compound interest.
- (4.3) The rate of interest used is 7% per annum.

This leads to the equation:

$$A \cdot \frac{(1+i)^{20} - 1}{i} = P \sum_{n=1}^{n=20} Q_n (1+i)^{20-n} \quad (1)$$

Where A is the total annual operating costs for the steam supply.

i = 0.07, the rate of interest

$Q_n$  the total steam consumption of the plant in the year n.

n the year of operation

P cost-price of the steam kr/ton

After computation of the term on the right hand side of equation (1) as shown in table (2), and the term on the left hand side:

$$A \cdot \frac{(1+i)^{20} - 1}{i} = 3.41 \frac{1.07^{20} - 1}{0.07} = 139.8 \text{ Mkr.}$$

the cost-price of the steam is found to be:

$$P = \frac{139.8 \times 10^6}{6,284 \times 10^3} = \underline{\underline{22.25 \text{ kr/ton of steam}}}$$

TABLE (2) COMPUTATION OF  $\sum_{n=1}^{n=20} Q_n (1+i)^{20-n}$

Year	$Q_n$ $10^3$ Ton/yr	$(1+i)^{20-n}$	$Q_n (1+i)^{20-n}$ $10^3$ Ton/yr
1968	42.4	3.62	154
69	63.7	3.38	215
70	84.7	3.16	268
71	98.8	2.95	292
72	127.1	2.76	351
73	141.3	2.58	365
74	169.4	2.41	408
75	197.7	2.25	445
76	211.8	2.11	445
77	211.8	1.97	417
78	211.8	1.84	390
79	211.8	1.72	364
1980	211.8	1.61	340
81	211.8	1.50	318
82	211.8	1.40	296
83	211.8	1.31	277
84	211.8	1.22	259
85	211.8	1.14	242
86	211.8	1.07	226
1987	211.8	1.00	212
	3466.7		6284

### (5) SELECTION OF TARIFF FOR THE STEAM

There are several methods of fixing the tariff for the sale of the steam. In our previous estimates (January and November 1965) it was proposed to use a tariff consisting of a fixed annual sum plus a charge on each ton of steam sold to the plant. This leads to rather high steam prices during the first years of operation, but they fall rapidly as the production increases.

Another method is to sell the steam at a fixed unit price computed as shown in the previous section (4). This would be more convenient to the factory in the first years.

The operating costs (refer section 3.2) estimate shows that the royalty on the steamfield, and the depreciation and interest on the capital, amount to 1.91 Mkr/yr, or about 56% of the total operating costs.

The direct cash out-lays amount to 1.00 Mkr/yr or 29.3%.

The post "reserve fund contribution" is intended to meet unforeseen emergencies, such as major renewal of equipment, and in particular a sudden failure of a borehole. In this connection it must be kept in mind that the production of geothermal steam involves considerable risks. An agency that is contractually bound to guaranty steady delivery of the steam must have cover for such risks in order to be able to meet its obligations at all times. The amount of 0.5 Mkr/yr or 14.6% of the total operating costs is considered reasonable and adequate for this purpose. Due to the very nature of this charge it seems logical to treat it as a cash-outlay in cash-flow calculations.

Table (3) shows the cashflow, and the overall balance for the steam supply system over the first 20 years. The calculations are based on the following tariffs:

TARIFF (1): Fixed annual charge of 1.00 Mkr/yr  
plus 16 kr/ton of steam

TARIFF (2): Fixed steamprice of 0.52 US\$/ton = 22.36 kr/ton  
of steam.

Table (4) shows that the annual payments placed on compound interest of 7% per annum give approximately the same capital worth at the end of 1987, as the annual operating costs placed on compound interest at the same rate.

Table (5) shows a detailed comparison between the two tariffs.

TABLE (3) CASHFLOW AND BALANCE FOR THE STEAM SUPPLY FOR 20 YEARS

Year	1968	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87
Sales of Steam	42.4	63.7	84.7	98.8	127.1	141.3	169.4	197.7	211.8	211.8	211.8	211.8	211.8	211.8	211.8	211.8	211.8	211.8	211.8	211.8
TARIFF (1)																				
1.00 Mkr/yr + 16 kr/ton																				
CASHFLOW																				
Annual Sales	1.68	2.04	2.35	2.58	3.03	3.26	3.71	4.16	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38
Cash Out-lays	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Difference	0.18	0.54	0.85	1.08	1.53	1.76	2.21	2.66	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88
Accumulated Cash	0.18	0.72	1.57	2.65	4.18	5.94	8.15	10.81	13.69	16.57	19.45	22.33	25.21	28.09	30.97	33.85	36.73	39.61	42.49	45.37
OVERALL BALANCE																				
Annual Sales	1.68	2.04	2.35	2.58	3.03	3.26	3.71	4.16	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38
Annual Costs	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41
Balance	-1.73	-1.37	-1.06	-0.83	-0.38	-0.15	0.30	0.75	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Acc. Balance	-1.73	-3.10	-4.16	-4.99	-5.37	-5.52	-5.22	-4.47	-3.50	-2.55	-1.56	-0.59	0.38	1.35	2.32	3.29	4.26	5.23	6.20	7.17
TARIFF (2)																				
0.52 \$/ton = 22.36 kr/ton																				
CASHFLOW																				
Annual Sales	0.95	1.42	1.90	2.21	2.84	3.17	4.42	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73
Cash Out-lays	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Difference	-0.55	-0.08	0.40	0.71	1.34	1.67	2.21	2.92	3.23	3.23	3.23	3.23	3.23	3.23	3.23	3.23	3.23	3.23	3.23	3.23
Accumulated Cash	-0.55	-0.63	-0.23	0.48	1.82	3.49	5.70	8.62	11.85	15.08	18.31	21.54	24.77	28.00	31.23	34.46	37.69	40.92	44.15	47.38
OVERALL BALANCE																				
Annual Sales	0.95	1.42	1.90	2.21	2.84	3.17	4.42	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73
Annual Costs	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41
Balance	-2.46	-1.99	-1.51	-1.20	-0.57	-0.24	0.30	1.01	1.32	1.32	1.32	1.32	1.32	1.26	1.32	1.32	1.32	1.32	1.32	1.32
Acc. Balance	-2.46	-4.45	-5.96	-7.16	-7.73	-7.97	-7.67	-6.66	-5.34	-4.02	-2.70	-1.38	-0.06	1.26	2.58	3.90	5.22	6.54	7.86	9.18

TABLE (4) CONTROL OF THE TARIFFS

Year	Interest coeff.	TARIFF (1)		TARIFF (2)	
		Payments Mkr.	Worth 1987 Mkr.	Payments Mkr	Worth 1987 Mkr.
1968	3.62	1.68	5.92	0.95	3.68
69	3.38	2.04	6.90	1.42	4.80
70	3.16	2.35	7.43	1.90	6.01
71	2.95	2.58	7.61	2.21	6.52
72	2.76	3.03	8.36	2.84	7.84
73	2.59	3.26	8.45	3.17	8.21
74	2.42	3.71	8.98	3.71	8.98
75	2.26	4.16	9.40	4.42	9.98
76	2.11	4.38	9.25	4.73	9.99
77	1.967	4.38	8.61	4.73	9.32
78	1.840	4.38	8.06	4.73	8.71
79	1.719	4.38	7.54	4.73	8.14
80	1.605	4.38	7.03	4.73	7.60
81	1.500	4.38	6.57	4.73	7.11
82	1.403	4.38	6.15	4.73	6.65
83	1.311	4.38	5.72	4.73	6.21
84	1.226	4.38	5.37	4.73	5.81
85	1.146	4.38	5.02	4.73	5.42
86	1.070	4.38	4.69	4.73	5.06
87	1.000	4.38	4.38	4.73	4.73
		75.37	141.44	77.38	140.77



TABLE (5) COMPARISON BETWEEN THE TARIFFS

							TARIFF (1)	TARIFF (2)
Steam costs for the plant in the								
1st year of operation				Mkr.		1.68	0.95	
2nd	-	-	-	-		2.04	1.42	
3rd	-	-	-	-		2.35	1.90	
4th	-	-	-	-		2.58	2.21	
5th	-	-	-	-		3.03	2.84	
Total for first 5 years of operation							11.68	9.32
-	-	-	20	-	-	75.37	77.38	
Production of Diatomite during								
first 5 years				tons		59,000	59,000	
-	20	-		-		481,000	481,000	
<u>Steam costs / ton diatomite:</u>								
First 5 years				kr/ton		198	158	
-	-	-		\$/ton		4.60	3.67	
-	20	-		kr/ton		157	160	
-	-	-		\$/ton		3.64	3.74	

(6) RETURNS ON THE INVESTED CAPITAL

In order to evaluate the tariffs found in the preceding section it is useful to calculate the returns on the capital invested in the steam supply system over the first 20 years.

The invested capital amounts to 13.2 Mkr. in 1967. The returns on this capital can be calculated in percent per annum, by iteration. This is done by finding the capital worth in 1967 of the net balance in the years 1968-1987.

The net balance is the difference between in the annual income (sales of steam) and the net operating costs as found in section (3.2) less the post "interest and depreciation".

The calculation is carried out in table (6), where the returns on the invested capital, based on Tariff (2) is found to be 9.32% per annum. This is only slightly higher than current rate of interest, and shows that the steam could not possibly be sold at lower prices than found in section (5).

If the steam supply would be relieved off paying the royalty on steamfield, the returns on the investment would be 11.13% per annum, as found in table (7).

Reykjavik 23 July 1966

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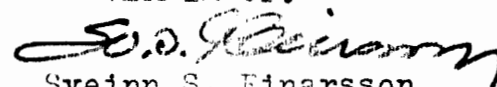
  
Sveinn S. Einarsson

TABLE (6) RETURNS ON CAPITAL INVESTED IN THE STEAM SUPPLY SYSTEM OVER FIRST 20 YEARS

Year	Investment Mkr.	Operating Costs Mkr.	Income (Sales) Mkr.	Balance Mkr.	Interest Coeff. 9 %	Worth 1967 Mkr.	Interest Coeff. 10 %	Worth 1967 Mkr.
1967	13.200			-13.200	1.000	-13.200	1.000	-13.200
68		1.80	0.95	- 0.850	0.917	- 0.779	0.909	- 0.773
69		1.80	1.42	- 0.380	0.841	- 0.320	0.826	- 0.314
70		1.80	1.90	0.100	0.772	0.077	0.751	0.075
71		1.80	2.21	0.410	0.708	0.290	0.682	0.280
72		1.80	2.84	1.040	0.650	0.677	0.620	0.645
73		1.80	3.17	1.370	0.596	0.817	0.564	0.773
74		1.80	3.71	1.910	0.547	1.044	0.512	0.979
75		1.80	4.42	2.620	0.502	1.315	0.466	1.222
76		1.80	4.73	2.930	0.461	1.350	0.423	1.240
77		1.80	4.73	2.930	0.422	1.236	0.385	1.130
78		1.80	4.73	2.930	0.388	1.137	0.350	1.026
79		1.80	4.73	2.930	0.356	1.042	0.318	0.932
80		1.80	4.73	2.930	0.327	0.960	0.289	0.848
81		1.80	4.73	2.930	0.300	0.879	0.263	0.772
82		1.80	4.73	2.930	0.275	0.806	0.239	0.702
83		1.80	4.73	2.930	0.253	0.742	0.217	0.636
84		1.80	4.73	2.930	0.232	0.681	0.198	0.581
85		1.80	4.73	2.930	0.213	0.624	0.180	0.528
86		1.80	4.73	2.930	0.195	0.572	0.163	0.478
1987		1.80	4.73	2.930	0.179	0.525	0.148	0.434

== -1.006 ==

== 0.475 ==

0.475

Return = 9 +  $\frac{0.475}{1.006}$  = 9.32 % per annum

TABLE (7) RETURN ON CAPITAL

Year	Investment Mkr.	Operating Costs Mkr.	Income (Sales) Mkr.	Balance Mkr.	Coeff of interest 11% p.a.	Worth 1967 Mkr.	Coeff of interest 12%	Worth 1967 Mkr.
1967	13.20			-13.20	1.000	-13.200	1.000	-13.200
68		1.50	0.95	- 0.55	0.901	- 0.496	0.893	- 0.491
69		1.50	1.42	- 0.08	0.812	- 0.006	0.797	- 0.006
70		1.50	1.90	0.40	0.731	0.283	0.712	0.285
71		1.50	2.21	0.71	0.659	0.468	0.636	0.452
72		1.50	2.84	1.34	0.594	0.796	0.567	0.760
73		1.50	3.17	1.67	0.535	0.884	0.507	0.846
74		1.50	3.71	2.21	0.482	1.068	0.452	0.999
75		1.50	4.42	2.92	0.434	1.269	0.404	1.182
76		1.50	4.73	3.23	0.391	1.262	0.361	1.167
77		1.50	4.73	3.23	0.352	1.138	0.322	1.040
78		1.50	4.73	3.23	0.317	1.023	0.288	0.931
79		1.50	4.73	3.23	0.286	0.925	0.257	0.830
80		1.50	4.73	3.23	0.256	0.828	0.229	0.740
81		1.50	4.73	3.23	0.232	0.750	0.207	0.668
82		1.50	4.73	3.23	0.209	0.676	0.183	0.591
83		1.50	4.73	3.23	0.188	0.607	0.163	0.526
84		1.50	4.73	3.23	0.170	0.549	0.146	0.472
85		1.50	4.73	3.23	0.153	0.494	0.130	0.420
86		1.50	4.73	3.23	0.138	0.446	0.116	0.375
1987		1.50	4.73	3.23	0.124	0.401	0.104	0.336
						<u>0.165</u>		<u>1.077</u>

$$\text{Return} = 11 + \frac{0.165}{0.165 + 1.077} = 11.13\% \text{ p.a.}$$