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November 12, 2010

Prof. Dr. Christian Wolkersdorfer
Chair in Mine Water Remediation & Management
Cape Breton University
1250 Grand Lake Road
Sydney, NS B1P 6L2

Dear Professor Wolkersdorfer:

A recent news item about a Cape Breton Island interest in geothermal energy recovery from abandoned coal mine workings sent me scurrying to dig out some of my old research and consulting files. In this connection, I presume that you are well aware of the Springhill experience of this type of operation.

I am a chemical engineer with an energy-related industrial background and a professor emeritus in the Department of Chemistry of Saint Mary's University and, in 1996, Natural Resources Canada retained my services to provide advice on dealing with certain problems that were being encountered in the Springhill operation.

I have not maintained contact with the folks at Springhill and my knowledge of the status of that system is now completely out of date. However, the early teething problems of that system should be of interest to anyone contemplating installing a new system today.

The attached examples of our reports on these problems may therefore be of interest. Please feel free to make use of them in any way you see fit.

When the Springhill mines were shut down, a good deal of iron and steel equipment left behind where it gently dissolved in the anoxic, acidic waters present in the lower mine levels. However, presumably due to fresh water infiltration, the water was slightly aerobic and essentially neutral at the level at which it entered the pipelines. Consequently, pipeline plugging by hydrated iron (III) oxide was a moderately serious problem, and one of the attached reports discuss measures for tackling with this problem.

Iron oxide solids buildup was most severe in the pipeline immediately above level at which the water pump was suspended in the pipeline. The length of the various pipeline ranged from 40 to 80 m and the pumps were located from steel cables at a depth close to the pipeline inlet. (In at least one instance a supporting cable corroded through dropping the pump into the bottom of the mine.

One of my regrets about this project was my failure to teach a lesson about the nature of cavitation, the fact that you can only lift water with a pump to a height of about 10 m . . . above this level, water "boils" at atmospheric temperature and the pump cavitates. For this reason it was held that the pumps had to be located close to the bottom of the pipeline which exacerbated a number of problems. This "reasoning" is of course fallacious. The pump may be located high in the pipeline at a level such that the friction head loss in the length of pipeline below the pump location is less than 10 m water gauge. Actually it is a bit more complicated than that (see Section 6.2 of the "Exploratory Investigation . . ." report).

Sincerely,

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?. Thomas: "pasteurisation" of FeOx ?

2010-11-15

APPLIED
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REMOVAL OF IRON OXIDE DEPOSITS FROM MINEWATER PIPELINES IN THE GEOTHERMAL ENERGY SYSTEM IN SPRINGHILL, NOVA SCOTIA

Background Notes for a Research Contract Proposal

submitted to
Natural Resources Canada
CANMET - ERL Division

by

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Report No. SMUAFRC-96-03
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SUMMARY

Abandoned water-filled mines appear to offer a fairly widespread geothermal energy resource in Nova Scotia and elsewhere, and resolution of the pipeline fouling problems currently being encountered in the Springhill, Nova Scotia system should therefore be of wider interest. A demonstration treatment project is recommended at this site, which could also be used as a vehicle to display other state-of-the-art technologies.

In a previous report, the Advanced Fluids Laboratory of Saint Mary's University attributed pipeline fouling in the Springhill geothermal energy system to bacterially mediated oxidation of soluble iron(II) cations to insoluble iron(III) salts, and recommended an investigation of in-place pasteurization treatments. In the present report, hot water, electric heat and steam are considered as alternative energy sources to periodically pasteurize the bacteria responsible for the formation of these solids deposits.

Evaluated against a tentative treatment target of 10 minutes exposure to a temperature of at least 65 deg. C, batch filling of long well pipelines with hot water cannot provide adequate temperatures, continuous treatment with hot water would require an excessively large water heater and both procedures present serious practical implementation problems

In contrast, heating with a low-cost electric cartridge heater lowered through a gland in the well head into the pipeline appears to be a much more promising procedure, providing that the well pump can be kept running at a low flow rate (say 10% of normal delivery) during treatment. Relatively "positive" well pumps are installed because they must be capable of lifing water from the surface of the water table to ground level, and any attempt to reduce their deliveries by 90% by throttling a valve at the well head would likely lead to overheating of pump motors and would certainly produce inconveniently high well head pressures. However these problems could be overcome by installing adjustable speed drives on the existing ac induction pump motors, which would provide the required turndown without overheating or excessive pressure buildup.

We have not carried out a cost- benefit analysis, but we suspect that the installation of such drives would also prove beneficial to normal system operation and, in addition, would help to publicize the opportunities provided by this important available technology

Steam treatment would likely be highly effective because it would combine both heating and agitation. However, injecting steam down the pipeline to the pump against the hydrostatic head in the well would typically call for a supply pressure in excess of 100 psig. Under these conditions the surface of the plastic pipeline would be exposed to temperatures in excess of 170 deg. C.

A gentler treatment could be achieved by introducing a smaller amount of steam through a small diameter high pressure hose inserted down to the bottom of the pipeline, and this possibility merits further study providing that safety requirements of handling 120+ psig steam on site can be met.

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LIST OF FIGURES

1.0 INTRODUCTION

In a recent report by the Advanced Fluids Research Laboratory of Saint Mary's University entitled "Exploratory Investigation of Causes of and Remedies for Water Supply Line Obstruction Problems Encountered in Geothermal Systems Employing Iron-Rich Waters" (DSS Contract No: 23440-5-1080/01-SQ, March 31, 1996), we conclude that these solids buildup problems are due to bacterially mediated oxidation of soluble iron(II) cations to insoluble iron(III) deposits, and suggest that these deposits might be periodically removed by *in-place* pasteurization with hot water, electric heat or live steam //

The relative merits and shortcomings of these three heating strategies are analyzed and the related use of adjustable speed drives for well pump mpotors is discussed.

2.0 PASTEURIZATION WITH HOT WATER

One possible method of pasteurization of solids deposits on the inside wall of a well pump delivery pipe would be to turn the pump off and use a high-head pump at the surface to pump heated water down the pipe from above. (The same hot water source could also be used to cleanse above-ground components of the energy system).

However it is not entirely obvious how this might be done since much depends on the behavior of the non-return valve. If this check valve operates properly and closes to seal the line when the well pump is turned off, the hot water treatment can be applied over the whole length of the line by inserting a hot water supply hose down the line to the valve (no simple matter). On the other hand, if (as seems likely) the valve jams open, hot water can be pumped directly down the line by the surface pump (without using a hose), displacing the original contents of the line out through the inactive well pump. However, in this case, when the hot water supply pump is turned off, the level in the line will rapidly drain to that of the surface of the water table in the surrounding well, and the subsequent pasteurization treatment will then only be applied to the lower length of pipe.

Ignoring for the moment these practical difficulties and uncertainties, it is useful to try to determine whether it is thermally practical to carry out an in-place pasteurization treatment in a deep well.

The effectiveness of this treatment will depend both on the initial temperature achievable at the bottom of the pipe after the water flow has cooled somewhat during its passage down the pipe, and on the temperature levels that can subsequently be maintained in the pipe after the supply pump has been turned off. The optimum temperature profile for pasteurization is unknown but hotter for a longer period is obviously better. A reasonable target would be achievement of a temperature of at least 65 deg. C for at least 10 minutes.

An ordinary electrically heated domestic hot water tank would be a convenient portable, source of hot water. The maximum capacity normally available is 0.27 m^3 (60 imperial gallons) with a thermostat setting adjustable to 70 deg. C. This temperature is clearly inadequate and it will be assumed that a temperature of 85 deg. C can be achieved by overriding the thermostat. A 100 m length of 0.0476 m (1.875 inch) internal diameter pipe would hold a volume of 0.18 m^3, which is within the capacity of the tank.

To model thermal performance, it will be assumed that

i) the "outside" well water temperature Tw is constant of the length of the pipe and is unaffected by the injection of hot water into the well

ii) hot water is pumped down the pipe at a mass rate m until steady state thermal conditions are achieved;

iii) the hot water supply pump is then turned off and the treatment period clock is turned on at time t = 0;

iv) the pipeline is 100 m long and it remains full of stationary hot water throughout the treatment period;

v) the internal and external radii of the pipe are (R_I =) 0.0238 m and (R_O =) 0.0302 m respectively;

vi) the pipe is made of a rigid plastic material having a thermal conductivity of (k =) 0.25 W m^{-1} C^{-1};

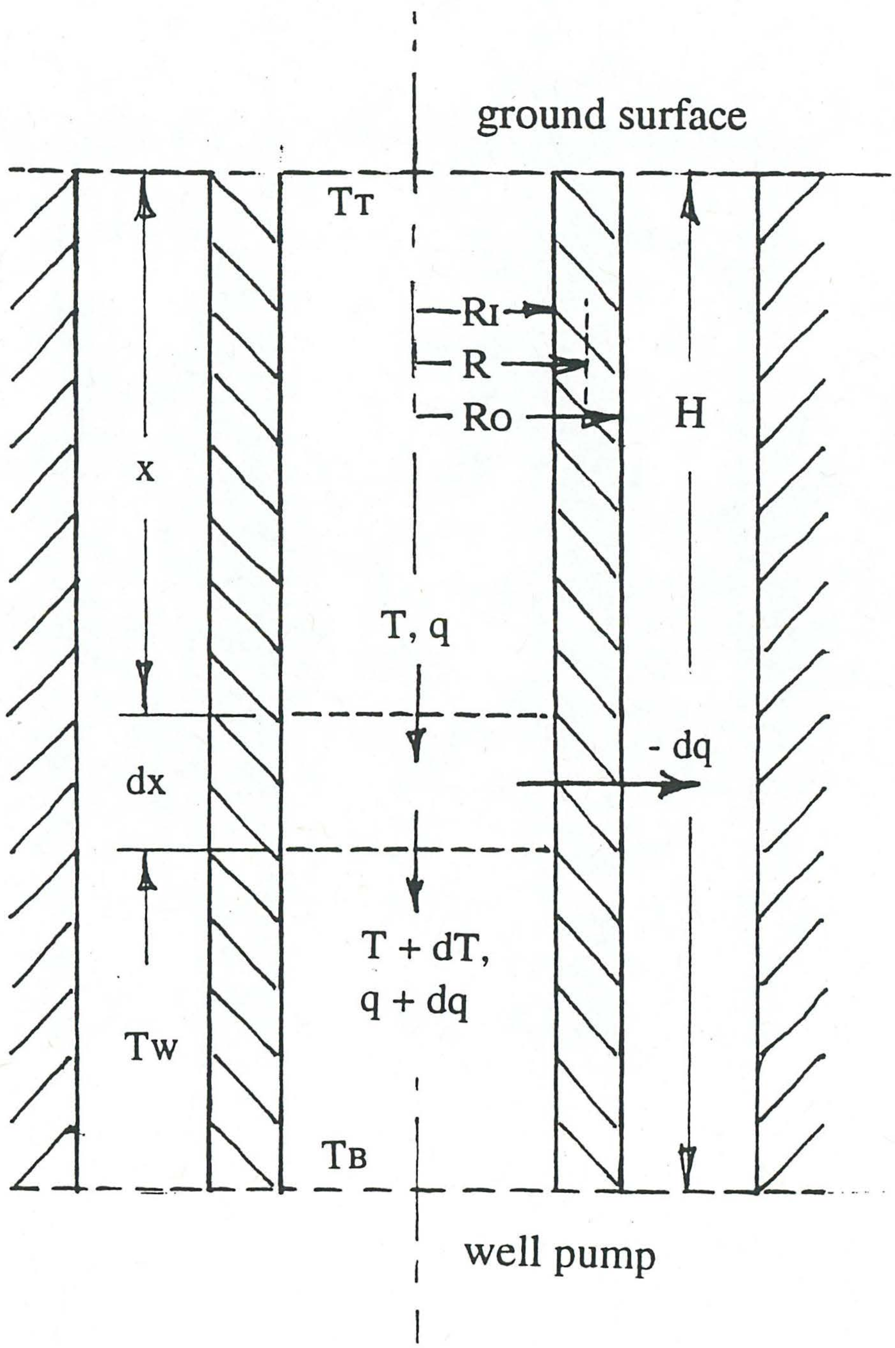
vii) the thermal resistances of the internal and external water films are negligible in comparison with that of the pipe wall

Under these conditions, the water temperature profile in the pipe at time t = 0 may be determined as follows. Referring to FIGURE 1, let

$q_{x,t}$	= heat flow rate down pipe at at depth x and time t
	= $q_{x,0}$ at t = 0
	= q for convenience
m	= mass flow rate of hot water down pipe (at t < 0)
$T_{x,t}$	= water temperature in the pipe at depth x at time t
	= $T_{x,0}$ at t = 0
	= T for convenience
$T_{0,t}$	= water temperature at depth x = 0 at time t
	= $T_{0,0}$ at t = 0 = T_T for convenience (T = top)
$T_{L,t}$	= water temperature at depth x = H at time t
	= $T_{H,0}$ at t = 0 = T_B for convenience (B = bottom)
T_P	= pipe wall temperature at radius R and x = x and t = 0

FIGURE 1

Well and Pump Delivery Pipeline Schematic



T_w = well water temperature (a constant)
R_I = internal radius of pipe (0.0238 m)
R_O = external radius of pipe (0.0302 m)
H = length of pipe (100 m)
k = thermal conductivity of pipe wall (0.25 W m^{-1} C^{-1})

Then the heat transfer rate through the pipe wall between depths x and x+dx at time t = 0

$$(q + dq) - q = 2\pi Rk(\{x + dx\} - x)(dT_P/dR)$$

Integrating this expression at depth x between $R = R_I$ and $R = R_O$,

$$\int_{T}^{T_W} dT_P = (dq/dx) / (2\pi k) \int_{R_I}^{R_O} dR/R$$

from which

$$T_W - T = (dq/dx) / (2\pi k) \ln(R_O/R_I)$$

from which

$$dq = - 2\pi k(T - T_w)dx / (\ln[R_O/R_I\})$$

$$= mC_P (\{T + dT\} - T)$$

Rearranging and integrating between x = 0 and x = x,

$$- 2\pi k / (mC_P (\ln\{R_O/R_I\}) \int_0^x dx = \int_{T_T}^{T} dT / (T-T_W)$$

$$- 2\pi kx / (mC_P (\ln\{R_O/R_I\}) = - \alpha x = \ln (\{T - T_W\} / \{T_T-T_W\})$$

from which the temperature at depth x a time t = 0 is

$$T = T_W + (T_T - T_W) \exp(- \alpha x)$$

and hence the temperature at the bottom of the pipe (x = H) at time t = 0 is

$$T = T_B = T_W + (T_T - T_W)\ \exp(-\ \alpha H)$$

in which the constant term

$$\alpha = 2\pi k\ /\ (\ mC_P\ (\ln\{R_O/R_I\})\ = 0.00157\ /\ m$$
$$= 0.0050\ m^{-1}\ \text{ for } m = 0.315\ kg\ s^{-1}\ (50\ USGPM)$$

Assuming a hot water supply temperature of 85 deg. C and a well temperature of 20 deg. C, the initial temperature profile in the pipe at time t = 0 is given by

$$T = 20 + 65\ \exp(-\ 0.0050x)$$

as follows:

0 meters	85.0 deg. C
20	78.8
40	73.2
60	68.2
80	63.6
100	59.4

The subsequent rates at which these temperature would fall after the hot water supply pump has been turned off (at t = 0) may be estimated as follows

The heat transfer rate through the pipe wall between x and and x + dx at time t (t > 0)

$$-\ dq\ =\ 2\pi k(T - Tw)dx\ /\ (\ln[R_O/R_I\})\ =\ -\ \rho\pi R_I^2 C_P (dT/dt)dx$$

from which

$$-\ 2k\ dt\ /\ (\rho\pi R_I^2 C_P \ln[R_O/R_I\})\ = -\ \beta dt\ =\ dT\ /\ (T - Tw)$$

Integrating between t = 0 and t = t,

$$-\ \beta \int_0^t dt = -\ \beta t = \int_{T_{x,0}}^{T_{x,t}} dT\ /\ (T\text{-}T_W) = \ln\ [(T_{x,t}\text{-}T_W)\ /\ (T_{x,0}\text{-}T_W)]$$

from which the water temperature at depth x at time t

$$T_{x,t} = T_W + (T_{x,0}-T_W) \exp(-\beta t)$$

in which

$$T_{x,0} = T_W + (T_{0,0}-T_W) \exp(-\alpha x)$$

and from which

$$T_{x,t} = T_W + (T_{0,0}-T_W) \exp(-\alpha x - \beta t)$$

$$= 20 + (85 - 20) \exp(-0.0050x - 0.00028t)$$

This relationship yields the following data which are plotted in FIGURE 2 :

x \ t	t = 0	t = 100	t = 200	t = 300	t = 400	t = 500	t = 600
0	85.0	82.6	80.3	78.1	75.9	73.8	71.8
20	78.8	76.6	74.5	72.4	70.4	68.4	66.5
40	73.2	71.2	69.2	67.3	65.4	63.6	61.8
60	68.2	66.3	64.5	62.7	60.9	59.2	57.6
80	63.6	61.8	60.1	58.4	56.8	55.2	53.7
100	59.4	57.7	56.1	54.6	53.1	51.6	50.2

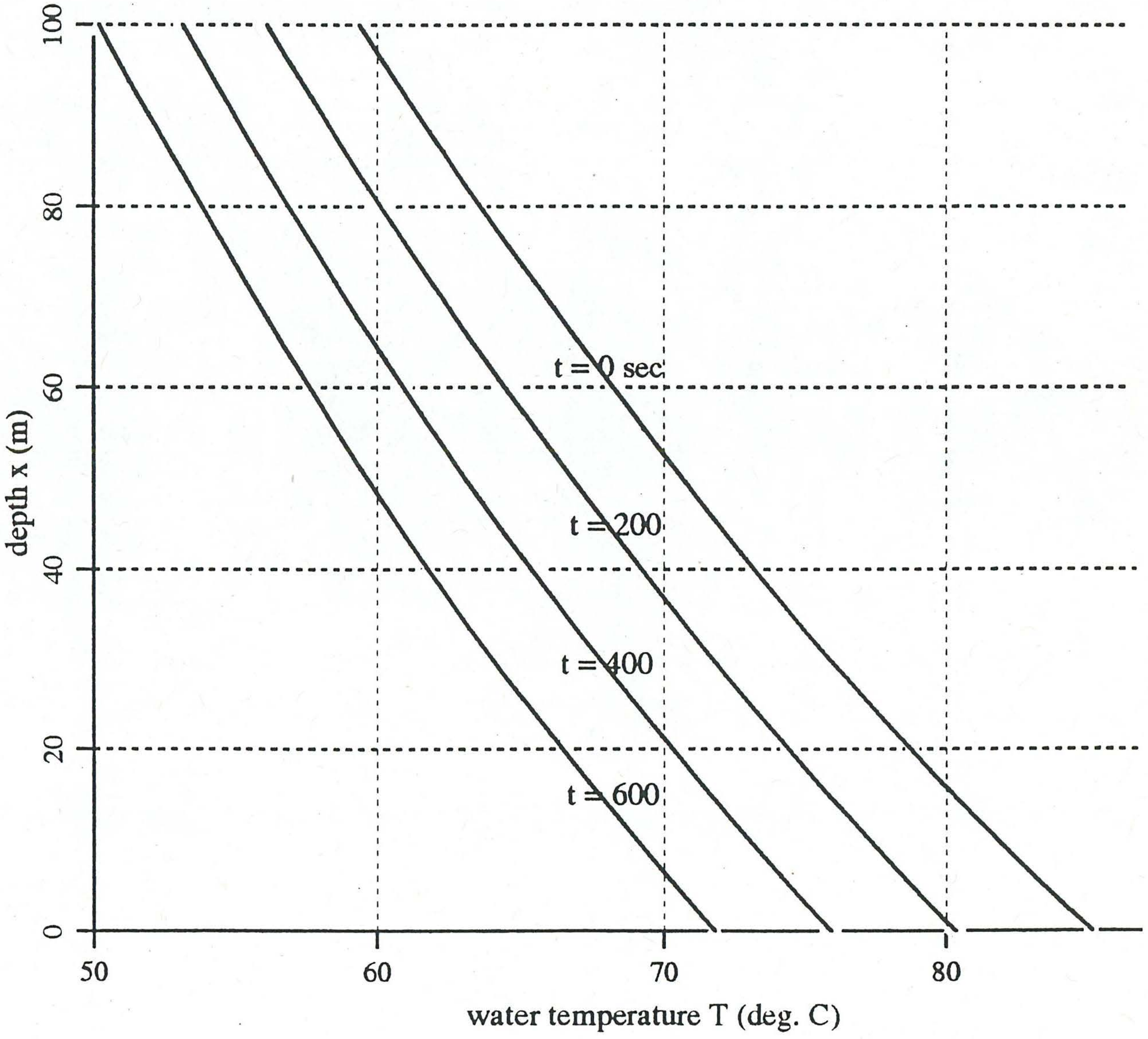
Our target of a temperature of at least 65 deg. C for at least 10 minutes (t = 600 sec) would clearly not be met in the bottom 80 m length of the well pipeline (and the supply wells in the Springhill system are generally somewhat deeper than the assumed depth of 100 m). Also, if the non-return valve "passed" and the water table level was at 20 m, the top 20 m of the well pipeline would not be treated due to drainage of the pipe contents down to this level when the hot water supply pump was turned off.

This procedure of <u>batch</u> addition of hot water does not seem to be a promising approach - - - although it might work with repeated treatments.

The alternative of <u>continuous</u> addition of hot water for a period of say 10 minutes would achieve and maintain the "t = 0" temperature profile. However this procedure would necessitate a much larger heating unit. To heat the assumed flow rate of 50 USGPM (m = 0.315 kg s^{-1}) continuously from 20 to 85 deg. C <u>would require an 85 kW heater</u>. The effects on the "t = 0" profile of reducing the hot water supply rate and hence, proportionally, the size of heater required are as follows:

FIGURE 2

Water Temperature as a Function of Depth and Time



x \ m	0 .315	0.300	0.250	0.200	0.150	0.100	0.050
0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
20	78.8	78.5	77.3	75.6	72.7	67.5	54.7
40	73.2	72.7	70.6	67.5	62.8	54.7	38.5
60	68.2	67.5	64.6	60.6	54.7	45.3	29.9
80	63.6	62.8	59.3	54.7	48.1	38.5	25.3
100	59.4	58.5	54.7	49.6	42.8	33.5	22.8

These data are plotted in FIGURE 3 .

3.0 PASTEURIZATION BY ELECTRICAL HEATING

The hot water-based procedures would seem to be marginally effective at best ~~and~~ present practical application difficulties relating to the behavior of the non-return valve and the problem of draindown in the pipe section above the surface of the water table.

A more promising approach would be to insert an electric heating element attached to a cable down to the bottom of the delivery pipe, and then withdraw it gradually upward through a gland in the well head. The procedure envisaged would involve keeping the well pump running to prevent emptying of the pipe above the water table level, but substantially lowering its delivery rate to reduce the capacity of the electric heater required. This procedure would also permit treatment of the ground level components of the system.

The delivery of the well pump might be reduced from a normal rate of say 0.315 kg s^{-1} (50 USGM) to a measurable "trickle" of say (m =) 0.0315 kg m^{-1} (5 USGPM) by throttling a valve downstream of the well head.

The Goulds model 48GS50 (Goulds Pumps (Canada) Ltd.) is representative of the type of submersible well pump used in the Springhill geothermal energy system, and the characteristics of the 48GS series of pumps are shown in FIGURE 4. From these data, the characteristic of the model 48GS50 pump (FIGURE 5) is

$$H_D = \Delta P_D / (\rho g) = - 0.05256Q^2 - 0.04886Q + 432.6 \quad \text{feet of water}$$

in which H_D (ft. of water) is the total dynamic head (pump delivery - suction pressure) and Q is the volumetric pump delivery rate (USGPM). Thus if the flow rate of this pump were to be throttled to Q = 5 USGPM by partial closure of a valve, the net pumping head (H_D) would be 431 ft (186 psi).

FIGURE 3

Water Temperature as a Function of Depth and Flow Rate

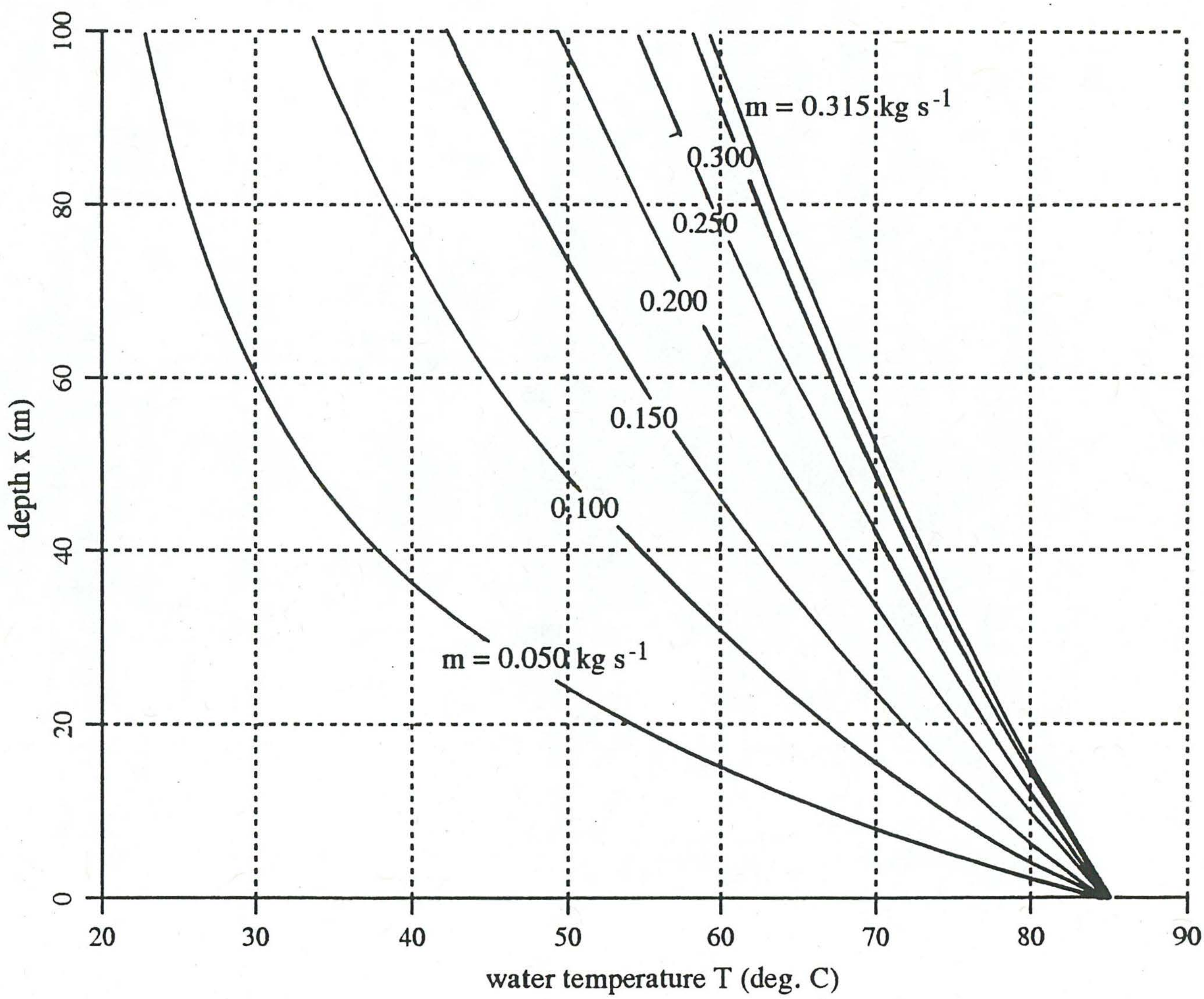


FIGURE 4

Well Pump Capacity and Performance

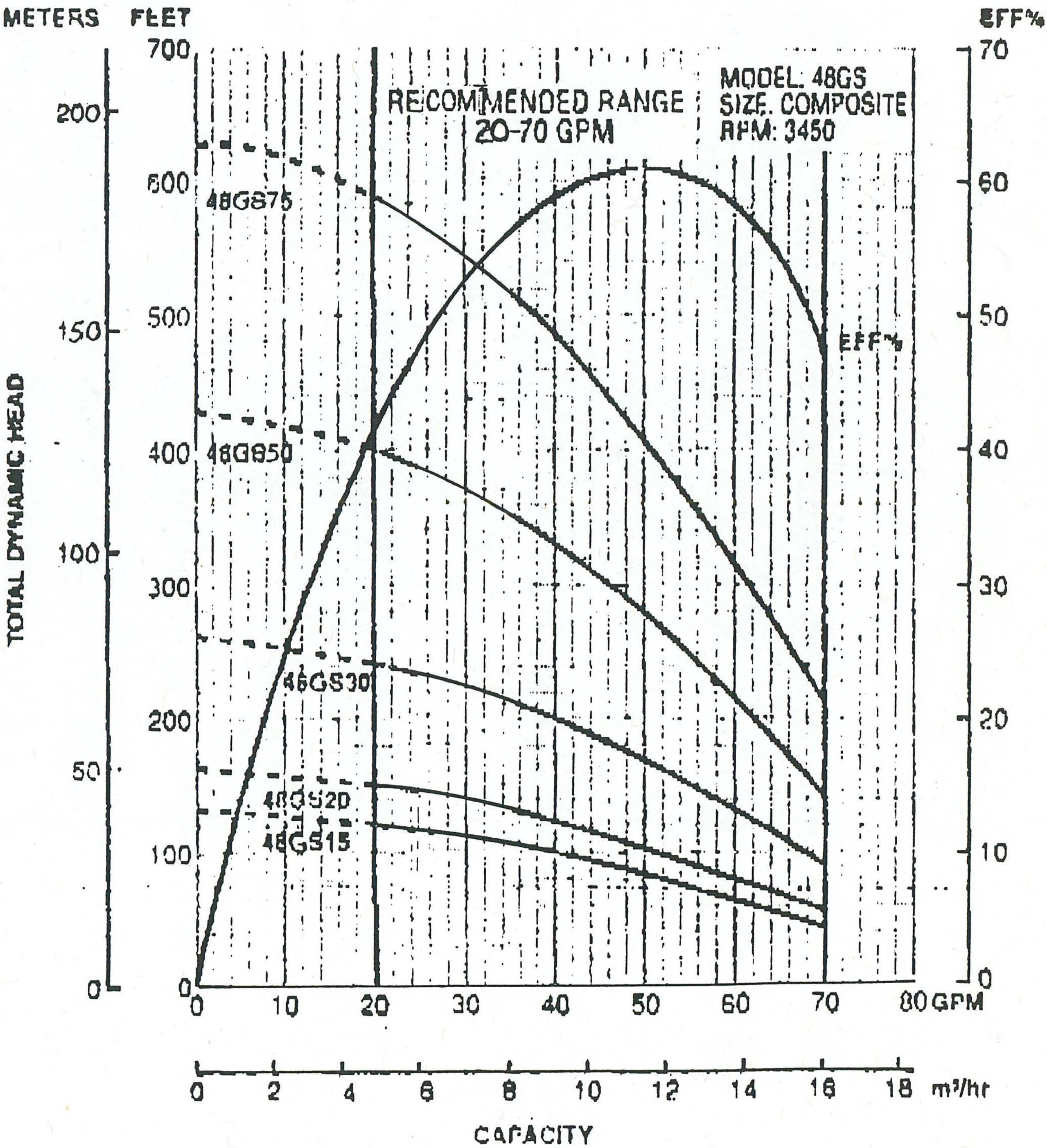
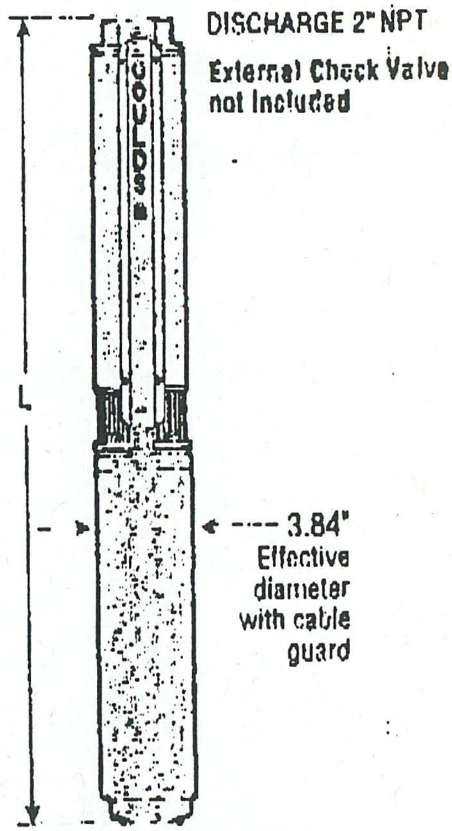
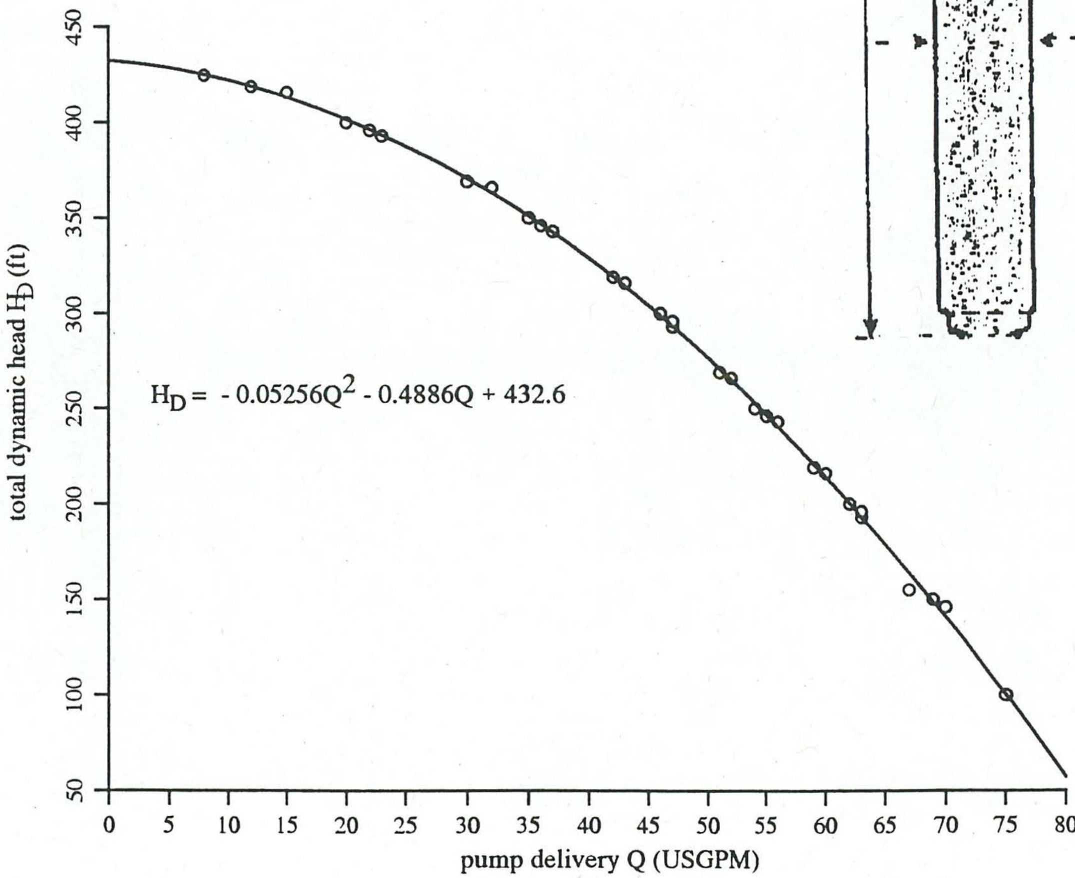


FIGURE 5

Performance Characteristic of the
Model 48GS50 Goulds Submersible Well Pump





The well head pressure P_{WH} is defined by the relationship

$$\Delta P_D = \rho g H_D = \rho g(H - (H - h)) + \rho U^2/2 + H(\Delta P_F/\Delta L) + P_{WH}$$
$$= \rho g h + P_{WH}$$

because the kinetic energy and wall friction loss terms will be negligible at very low flow rates. If the surface of the water table lies (h =) 20 m (66 feet) below the ground surface, the well head pressure will be 158 psi.

Trying to manipulate the heater cable through a gland in the well head against a water back pressure of more than 150 psi is not an attractive proposition. Thus throttling down the flow rate is impractical and, in any event, the manufacturer does not recommend operating the pump at rates below 20 USGPM (FIGURE 4), presumably to prevent overheating of the pump motor.

This appears to be an ideal application for an adjustable speed pump motor drive, and this topic will be discussed in SECTION 4.0.

In the electric heating case, the water flow will be up from the bottom up rather than down from the top, and it is therefore more convenient to measure distance x from the bottom up (FIGURE 6). If P is the power input per unit length of heater, the increase in the heat flow rate through the pipe between heights x and x + dx

$$(q + dq) - q = Pdx + 2\pi Rk(\{x + dx\} - x)(dT_P/dR)$$

Integrating this expression at depth x between $R_P = R_I$ and $R_P = R_O$,

$$\int_{T}^{T_W} dT_P = (dq/dx - P) / (2\pi k) \int_{RI}^{R_O} dR/R$$

from which

$$T_W - T = (dq/dx - P) / (2\pi k) \ln(R_O/R_I)$$

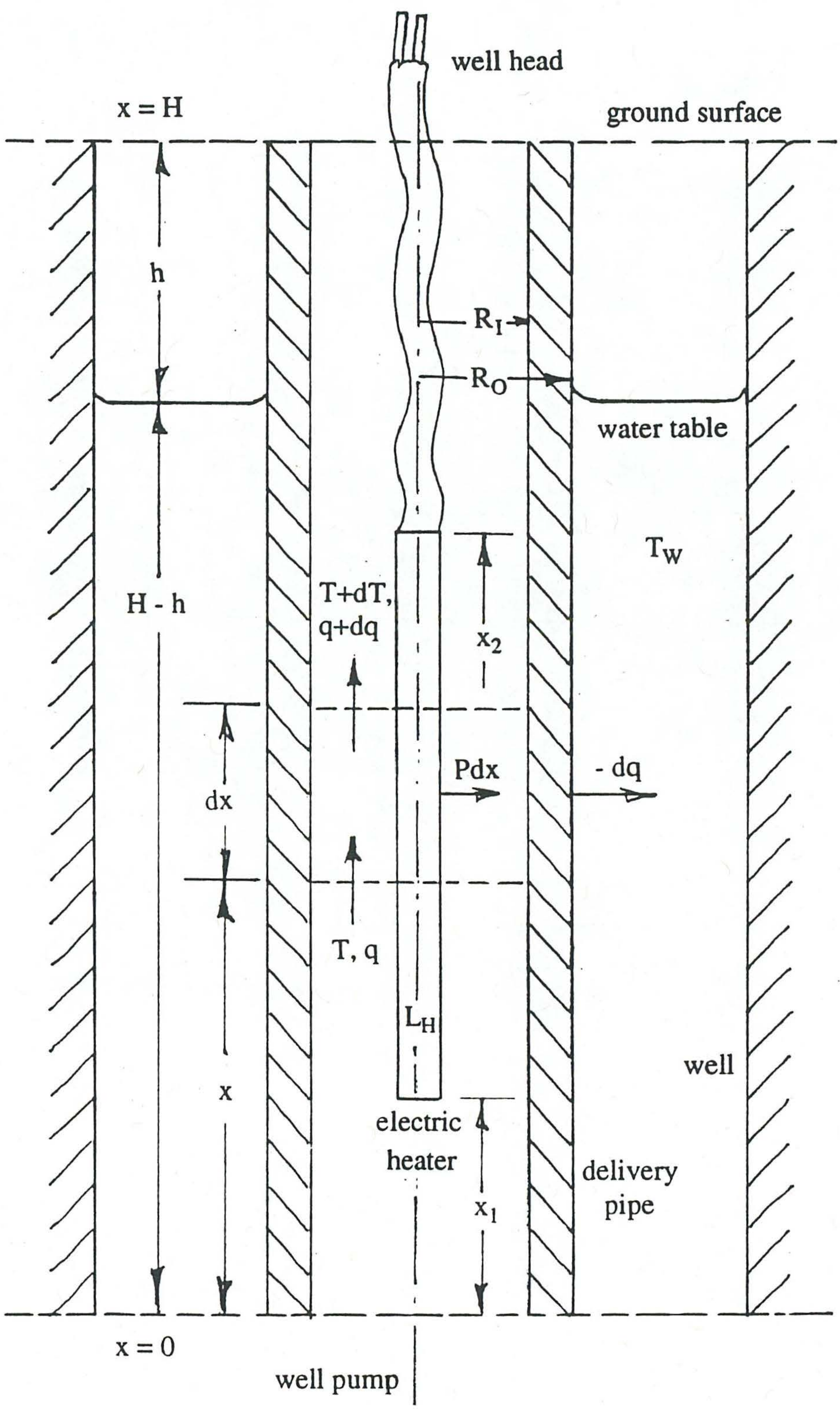
from which

$$dq = \{ P - 2\pi k(T - Tw) / (\ln[R_O/R_I])\} dx$$

$$= mC_P (\{T + dT\} - T\}$$

FIGURE 6

Well, Pump Delivery Pipeline, and Cartridge Heater Schematic



from which

$$\phi m C_P \, dT = -(T - \{Tw + \phi P\})\, dx \text{ in which } \phi = (\ln[R_O/R_I]) / (2\pi k)$$

Rearranging and integrating between x = 0 and x = x,

$$1/(\phi m C_P) \int_0^x dx = x / (\phi m C_P) = -\int_{T_0}^{T} dT / (T - [T_W + \phi P])$$

Referring to FIGURE 6, this integral covers three distinct zones

$0 < x < x_1$	for which P = 0 and $T = T_W$
$x_1 < x < x_2$	for which P = P and $T > T_W$
$x_2 < x < H$	for which P = 0 and $T > T_W$

For the zone below the heater, the temperature profile is given by $T = T_W$.
For the zone in which the heater is located

$$1/(\phi m C_P) \int_{x_1}^{x} dx = (x - x_1)/(\phi m C_P) = -\int_{T_1}^{T} dT / (T - [T_W + \phi P])$$

$$= \ln [([T_W + \phi P] - T) / (\phi P)]$$

in which $T_1 = T_W$ and from which the temperature profile is given by

$$T = T_W + \phi P \{1 - \exp[-(x - x_1)/(\phi m C_P)] \}$$

For the zone above the heater

$$1/(\phi m C_P) \int_{x_2}^{x} dx = (x - x_2)/(\phi m C_P) = \int_{T_2}^{T} dT / (T_W - T)$$

$$= -\ln [(T - T_W) / (T_2 - T_W)]$$

in which

$$T_2 = T_W + \phi P \{1 - \exp[-(x_2 - x_1)/(\phi m C_P)] \}$$

and from which the temperature profile is given by

$$T = T_W + (T_2 - T_W) \exp [-(x - x_2)/(\phi m C_P)]$$

$$= T_W + \phi P \{\exp[-(x - x_2)/(\phi m C_P)] - \exp [-(x - x_1)/(\phi m C_P)] \}$$

Omega Engineering's "Electric Heaters Handbook" (p. D-14) describes a 240 volt , 5 kW cartridge heater which is 4 feet long ($L_H = x_2 - x_1 = 1.22$ m) and has a diameter of 0.75 inch ($R_H = 0.00953$ m) and may be fitted with an integral thermocouple (product # CIR-5148/240; FIGURE 7)). For this heater, the power output per unit length $P = 4100$ W m^{-1}, and the value of

$$\phi = (\ln[R_O/R_I]) / (2\pi k) = (\ln[0.0302/.0238]) / (2\pi(0.25)) = 0.1516 \text{ C m W}^{-1}$$

from which $\phi P = 621.6$ C and $\phi m C_P = 634.4m$ metres.

For these conditions and $T_W = 20.0$ deg. C,

i) for $0 < x < x_1$

$$T = T_W = 20.0 \text{ deg. C}$$

ii) for $x_1 < x < x_2$

$$T = T_W + \phi P \{1 - \exp[-(x - x_1) / (\phi m C_P)] \} = 20.0 + 621.6\{1 - \exp[-0.001576(x - x_1)/m]$$

iii) for $x_2 < x < H$

$$T = T_W + \phi P \{ \exp[-(x - x_2) / (\phi m C_P)] - \exp[-(x - x_1) / (\phi m C_P)]$$

$$= 20.0 + 621.6 \{ \exp(-0.001576(x - x_2) / m) - \exp(-0.001576(x - x_1) / m)\}$$

Suppose that the flow rate is throttled from 50 USGPM to 5 USGPM ($m = 0.0315$ kg s^{-1}) and that the heater is located 10 m from the bottom of the well ($x_1 = 10.0$ m, $x_2 = x_1 + L_H = x_1 + 1.22 = 11.22$ m), then the maximum temperature will be reached at $x = 11.22$ m and will be

$$T = 20.0 + 621.6\{1 - \exp[-0.001576(11.22 - 10.0)/0.0315]\} = 56 \text{ deg. C}$$

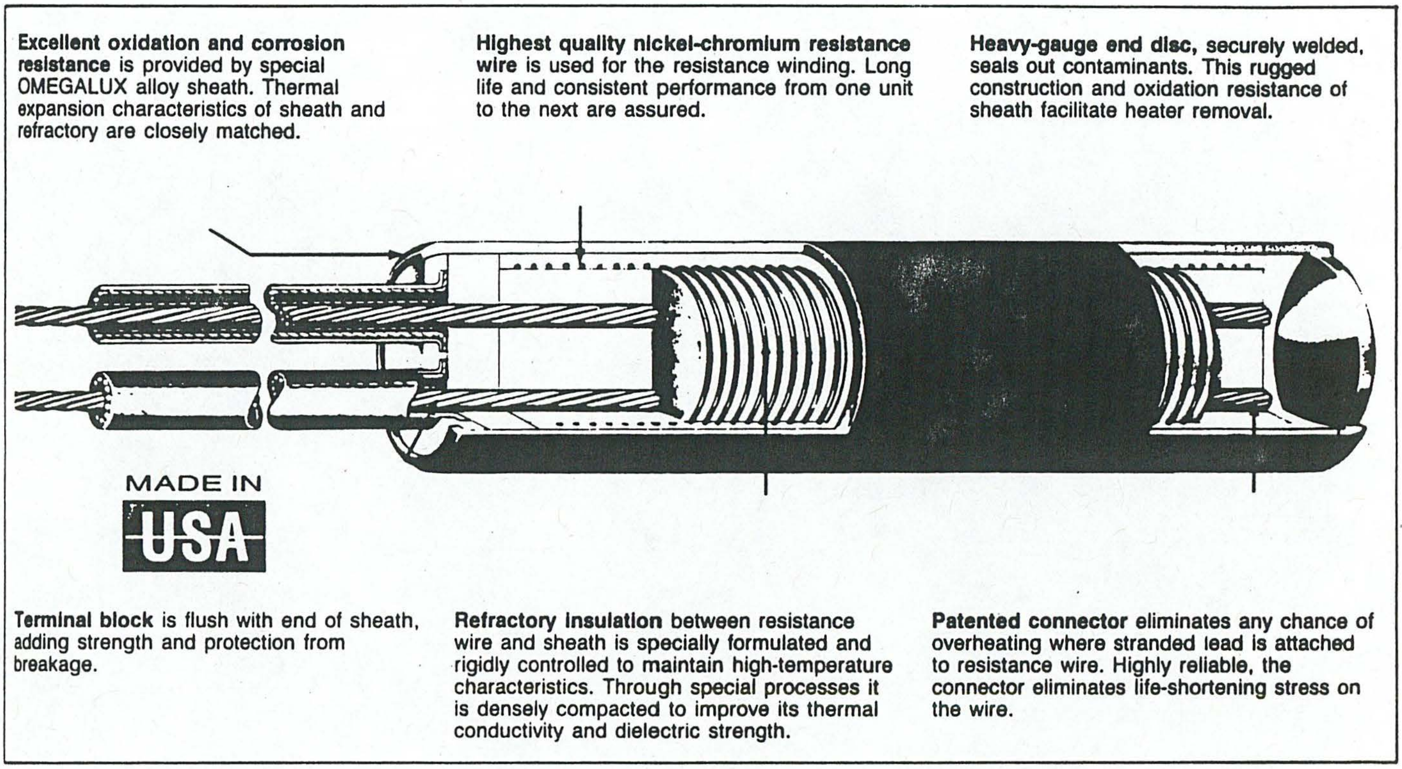
which is inadequate. Doubling the length ($L_H = 2.44$ m) and power output of the cartridge heater ($PL_H = 10000$ W), the maximum temperature will be reached at $x = 12.44$ m and will be

$$T = 20.0 + 621.6\{1 - \exp[-0.001576(12.44 - 10.0)/0.0315]\} = 91 \text{ deg.C}$$

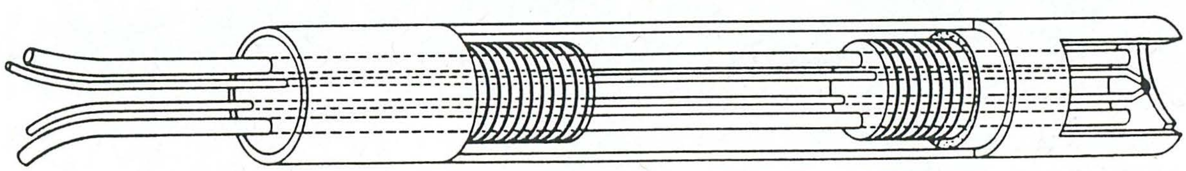
The temperature profiles for the pipeline over the height of the well for these two cartridge heaters are shown in FIGURE 8.

FIGURE 7

C Series Medium Watt Density Cartridge Heater
(Omega Engineering Incorporated)



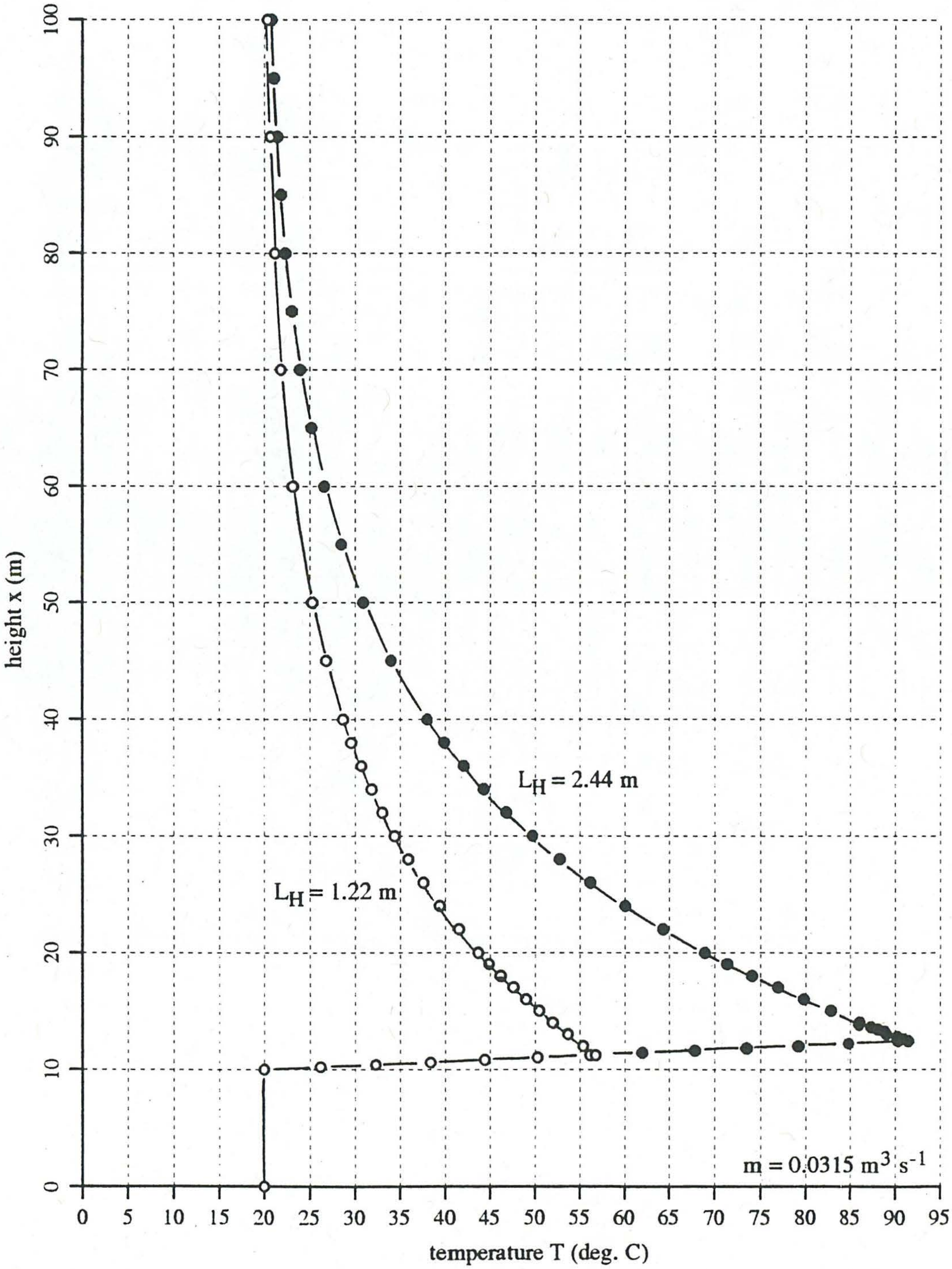
(a) Internal Construction Details. (NOTE: The cartridge heater will have to be custom fitted with a heavy duty cable, both to provide stiffness so that it can be pushed down into the well and to ensure low electrical resistance of its 400+ foot length. Also, an 8-foot long heater cartridge will be required which is twice the longest standard length currently provided by the manufacturer (Model CIR-5480/240)).



(b) Cartridge heater custom fitted with an internal thermocouple to provide overheating protection and to permit measurement of the water treatment temperature (after the heater has been turned off). (NOTE: To provide protection against overheating due to raising the heater out of the water, the thermocouple should be located at the top rather than at the bottom of the heating element).

FIGURE 8

Effect of Heater Capacity on the Pump Pipeline Temperature Profile



For the region in the vicinity of the heater, the effect on the temperature profile of heater capacity is shown in FIGURE 9(a) and the effect of water flow rate is shown in FIGURE 9(b). From these relationships, "possibly effective" and "probably effective" treatment zones may be defined as follows:

Heater Capacity (kW)	Flow Rate ($m^3 s^{-1}$)	Possibly Effective Length (T > 50 C)	Probably Effective Length (T > 65 C)
5	0.0630	0.0	0.0
5	0.0315	5.3	0.0
10	0.0630	7.3	0.0
10	0.0315	18.2	10.2

A stepwise treatment is therefore envisaged in which the electric cartridge heater is inserted through a well head gland and then progressively lowered down the pipeline as treatment proceeds, with the well pump operating at a low flow rate to keep the pipeline full of water.

Two important assumptions underly this proposed treatment procedure, namely

i) that the thermal conductivity of the pipe material is no higher than 0.25 W m^{-1} C^{-1}. and that this material can withstand surface temperatures as high as 100 deg. C;

ii) that a stable pump delivery rate of 5 USGPM (or lower) can be maintained at a well head pressure which is low enough to prevent excessive leakage of water out of the gland through which the heater cable is being fed into the pipeline.

The thermal properties of the plastic pipe used should be checked with the manufacturer but this assumption appears in any event to be acceptable since, during the treatment period, the inside of the pipe will be coated with a layer of deposited solids which will further increase the thermal resistance between the hot water in the pipe and the cool water in the surrounding well.

The second assumption is more critical because the stated conditions cannot be met by reducing the normal pump delivery rate by throttling a valve located downstream of the well head. The only practical approach appears to be reduction of the pump motor speed.

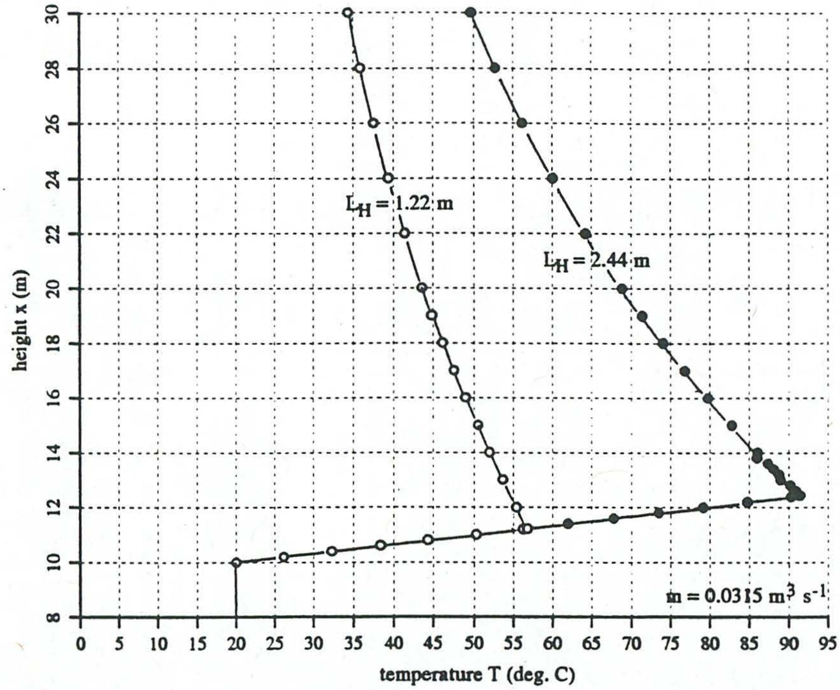
4.0 ADUSTABLE SPEED DRIVES FOR AC INDUCTION MOTORS

> *"The control of the speed of an electric motor from a state of rest to a state of full speed is a problem of rapidly growing importance to the electrical engineer"*

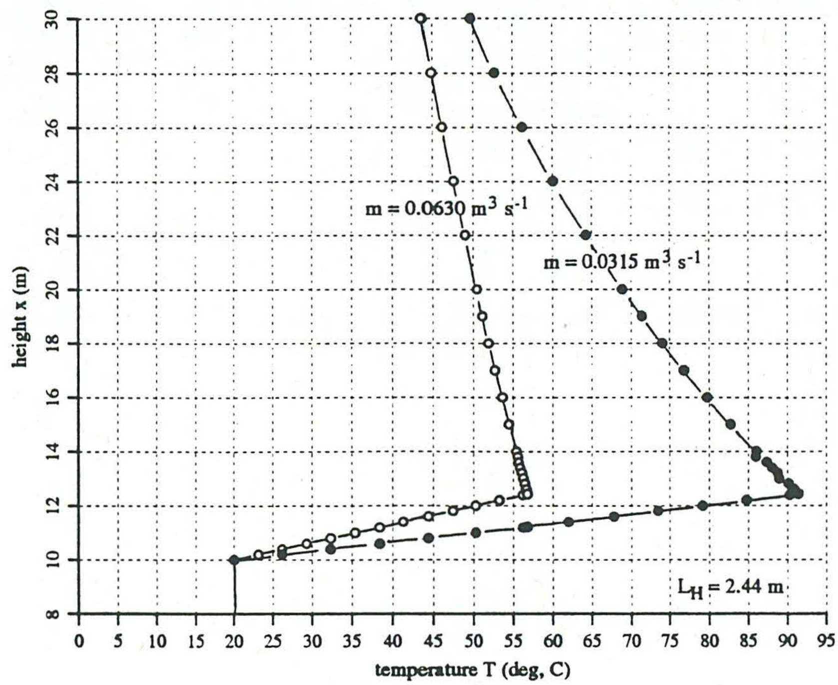
(Harry Ward Leonard in a speech to the American Institute of Electrical Engineers in November 1896, quoted by Jones, B. L., & J. E. Brown, *IEE Proc.* **131A**: 516-58 (1984)).

FIGURE 9

Pump Pipe Line Temperature Profiles



(a) Effect of Heater Capacity at Constant Water Flow Rate



(b) Effect of Water Flow Rate at Constant Heater Capacity

It seems that electrical engineers have now addressed Mr. Leonard's concern because the 1995 edition of the "Thomas Registry of American Manufacturers" lists numerous manufacturers and suppliers of "drives: adjustable speed a.c.".

In a review of "The Materials Revolution and Energy Efficient Electric Motor Drive Systems" (Baldwin, S. F., *Ann. Rev. Energy*, 1988, **13**: 67-94), the author notes that

> . . . a crucial factor in achieving higher efficiencies in motor drive systems is the ability to precisely control motor speed. One technique is to resynthesize the power going into an induction motor at an adjustable frequency. Adjustable speed electronic drives (ASD) driven by mercury arc rectifiers such as thyratrons and ignitrons were designed and tested in the 1930s, but found little acceptance because of their high cost and inconvenience. The development of solid-state devices with large power handling capabilities, reductions in device costs, and rising electricity prices have made solid-state electronic motor drives both possible and increasingly desirable. By 1986, more than 200,000 ASDs ranging in size from approximately 0.25 to 67,000 hp had been sold in the United States.

We are currently investigating the availability and cost of ASDs suitable for varying the speeds of the well pumps in the Springhill geothermal system.

5.0 PASTEURIZATION WITH STEAM

Steam is potentially attractive as a cleaning medium because of its high volumetric heat capacity, and because it injection into water would combine heating with agitation which should help erode the solids deposits on the pipeline wall.

Steam must be supplied at a pressure sufficient to expel water from the pipeline downwards and out through the pump which should be turned off. If the pump is located at a depth of 100 m and the surface of the water table lies 20 m below the ground surface, the required steam pressure at the bottom of the pipeline is approximately 120 psig. At this pressure, the condensation temperature of steam is 177 deg. C.

The heat transfer rate through the pipe wall between x and and x + dx

$$- dq = 2\pi k(T - Tw)dx / (\ln[R_O/R_I\})$$

$$= 2\pi(0.25)(177 - 20)dx / (\ln[0.0302/0.0238])$$

$$= 1040 \text{ dx W m}^{-1}$$

which is equivalent to approximately 100 kW for a pipelength of 100 m. The latent heat of fusion of steam at 120 psig is approximately 2000 kJ kg-1 and hence the required rate of supply of steam is 0.20 kg s^{-1} (1500 lb hr^{-1}).

This would be a highly effective treatment procedure, but it is uncertain that the pipe and particularly the pipe joints could withstand a pressure differential of 120 psig (at the top of the pipeline) combined with a surface temperature of 177 deg. C.

A gentler treatment could be achieved by introducing a smaller amount of steam through say an 0.75 inch I.D. high pressure "rubber" hose inserted down to the bottom of the pipeline. Again the supply pressure and temperature would have to be the same but the steam flow rate would be reduced somewhat more than in proportion to the 84% reduction in cross-sectional area from that of the pipe (2.76 in^2) to that of the hose (0.44 in^2). This procedure merits further study providing that safety requirements of handling 120+ psig steam on site can be met.