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GEOTHERMAL SOIL HEATING IN ICELAND

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ABSTRACT

The climate of Iceland is such that only hardy vegetables can be grown in the summer. Common crops are potatoes, carrots, cabbage and cauliflower. Soil heating using geothermal water has been practiced in Iceland for several years. Growing on naturally warm land in geothermal areas has, however, been known for a much longer time. Vegetable growing on warm land has proven to be very attractive and several new systems have recently come into operation. The practice is to heat the soil with low-temperature geothermal water that flows in plastic pipes buried at 50-80 cm depth and spaced 120-200 cm apart. An engineering study was undertaken to quantify the main parameters that govern heat transfer from parallel pipes in soil. Measurements from operational geothermal soil heating systems were compared to model calculations. Design guidelines have been prepared.

INTRODUCTION

An interesting task faces the geothermal community in Iceland. Within a few years the district heating market is likely to be saturated with about 80% of all homes using geothermal hot water. This success, then, raises the question: What other uses are there for geothermal energy in Iceland? Electric power generation is not the answer because the country is rich in hydropower resources. The task, therefore, is to find new uses for the geothermal resources of Iceland to continue the growth of the economy.

Soil heating is one of several new uses of geothermal energy receiving attention in Iceland, and for a very good reason - the climate. It is the heating of soil for horticultural purposes using geothermal water flowing in buried pipes and other conduits. Modest quantities of common vegetables have been grown in Iceland for a long time. Geothermal energy is extensively used in greenhouses in Iceland. The greenhouse industry, however, may suffer the same situation as does district heating; market saturation.

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This paper reports some applied research work that was undertaken to promote the development of geothermal soil heating in Iceland. The main aims of the work were to characterize the salient heat transfer features of operating soil heating systems and, to develop practical design methods for horticultural advisors and commercial growers. The work was carried out in parallel with trials to demonstrate the effect of soil heating on common vegetables.

Geothermal research and development in Iceland have been discussed by Fridleifsson (1982). Gudmundsson (1982a) discusses the utilization of low-temperature resources in Iceland. The uses of geothermal energy in horticulture is reported in Gudmundsson (1982b). Leifsson and Gudmundsson (1981) prepared design guidelines for pipe-heated fields utilizing geothermal water.

HORTICULTURE

The greenhouse industry in Iceland is well established with about 145,000 m^2 under glass. Geothermal energy is used in all the greenhouses, as would be expected. The greater part of the greenhouses are located in three main areas: one town and two rural. The best known of these is the town of Hveragerdi in the southwest of Iceland with about one-quarter of all the greenhouses. The rural areas are Borgarfjordur in the west and Arnessysla in the south. Tomatoes and cucumbers are grown in one-half the greenhouses and flowers in the other half.

Warm soil suitable for vegetable growing is associated with many hot springs and other geothermal features. The first recorded attempt to take advantage of warm soil for growing dates back to the middle 1850s. Since that time there have been many examples of small scale growing in naturally heated soil. One disadvantage with this method is the lack of temperature control. The first soil heating system was built in the late 1880s. About 1500 m^2 were heated by flowing geothermal water in closed conduits buried in the soil. Other similar systems were built in the years and decades that followed, all in the north of Iceland. It appears that soil heating did not catch on at that time because further development did not occur.

The greenhouse industry in Iceland began developing in the 1940s and so did the growing of vegetables in open fields. Potatoes have been a common crop in Iceland for two centuries and turnips have been grown for a long time. The vegetables that are of interest in soil heating, and are generally grown in open fields, are cabbage, carrots and cauliflower. In commercial growing the practice is to start these crops in a greenhouse one to two months before planting. This means that vegetable growing in Iceland is best carried out in or near a geothermal area.

At Fludir, in the south of Iceland, there has developed a community around an active geothermal area of many hot springs. The community is a typical example of how geothermal resources affect rural developments in Iceland; their main source of income is horticultural activities. There are large areas naturally heated at Fludir, some of which are used for vegetable growing. The soil temperatures at one meter depth are shown in Figure 1. Produce from this area arrive to market about two weeks earlier than elsewhere.

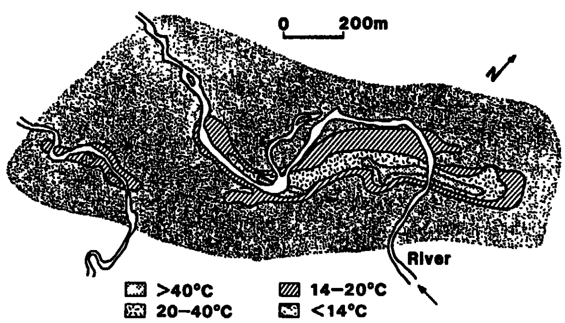

Figure 1. Isotherms at 1 m depth at Fludir geothermal area.

In the early 1950s the first soil heating system was built at Fludir; in a sense extending the naturally warm land. This system is still in operation and has recently been enlarged and is now about 6000 m^2. Water from a nearly hot spring is allowed to flow in several parallel conduits (lined with flat rock) approximately 30x30 cm, and buried with 50-60 cm of soil; the conduits are spaced 150-200 cm. The hot water seaps into the soil and drains away.

A new soil heating system was built at Fludir a few years ago; it has plastic pipes instead of a drainage system. The field is 250 m long and 30 m wide (7500 m^2) and is heated with six U-pipes where the hot and warm legs are side-by-side, as shown in Figure 2. Geothermal water at 93^{o}C flows by gravity from a nearly hot spring and is distributed equally between the six pipes. Almost identical soil heating systems have since been installed in two more fields at Fludir; these are 2800 m^2 and 4600 m^2. Two other growers use the discharge water from their greenhouses to heat 2500 m^2 and 3000 m^2 vegetable fields.

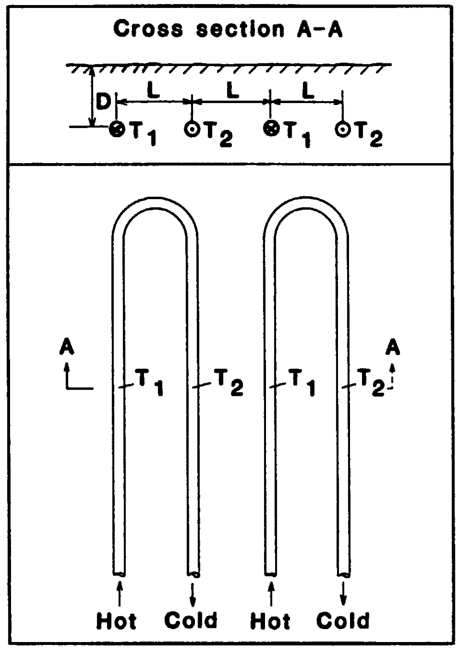

Figure 2. Layout of a typical soil heating system.

CLIMATE AND PRODUCE

The climate in Iceland is rather harsh for the growing of common vegetables; the average annual temperature in the Reykjavik area is below 5^{o}C. While potatoes grow best at temperatures below 20^{o}C, the optimum temperature for most other vegetables is in the range of 20-25^{o}C. Weather data for Reykjavik in May-September are shown in Table 1. The average and maximum air temperatures during spring and summer are clearly well below that needed for optimum growth of common garden vegetables. In July, the warmest month, records show that three nights of freezing are to be expected. However, the global radiation is comparable to other northern European countries with warmer climates.

Table 1: Weather Data from Reykjavik

	May	June	July	Aug.	Sept.
Air temp., ^{o}C	6.9	9.5	11.2	10.8	8.6
Max. temp., ^{o}C	--	11.0	13.0	12.8	9.7
Frost nights	15	5	3	5	14
Rain, mm	41	44	51	73	72
Radiation MJ/m^2	15.1	16.8	16.8	11.6	7.7

Commercial vegetable growers in Iceland market about one-half of their produce through a cooperative company. Table 2 shows the quantities of carrots, cabbage and cauliflower that the company received from growers in 1980. The table shows that fresh vegetables grown in Iceland are available for only a few months per year; the seasonal variation is clear. Although the tonnages are low, this production and that distributed by other means, apparently satisfy the demand for vegetables in the summer. For the rest of the year, vegetables have to be imported.

Table 2: Vegetables Received by Growers Cooperative Company in 1980 (tonnes)

	Carrots	Cabbage	Cauliflower
May	1.1	--	--
June	11.1	19.0	--
July	5.7	55.5	2.9
Aug.	15.3	25.8	34.7
Sept.	6.8	46.9	20.3
Oct.	8.8	--	6.2
Total	48.8	147.2	64.1

The growing conditions for garden vegetables in Iceland can be improved in two basic ways: sheltering the fields from wind and heating the soil. Recent experiments using wind breakers in potato fields have shown that production increases of 20-60% can be achieved. A third method should also be mentioned; plastic film cover. This method has shown similar improvements in yield as the others but it is labor intensive. The advantages and disadvantages of all the methods are now being evaluated in Iceland with respect to several crops.

The reasons for installing a soil heating system in Iceland are threefold: (1) Increase total yield, (2) obtain produce earlier and, (3) grow new varieties. The commercial growers aim at lessening the risk of crop failure due to changeable weather conditions from year to year. An interesting facet of soil heating is the possibility of growing varieties that keep better in storage. These tend to be slow in growing and not well suited for conditions in Iceland. The time of year when locally grown vegetables are available can therefore be extended in both directions; spring and autumn/winter.

EXPERIMENTAL WORK

An early observation in this work was that vegetables are sensitive to soil temperature. Carrots grown in temperatures above optimum became wide and plump, but did not penetrate the soil. Commercial growers, therefore, need to be rather careful in controlling the soil temperature. This point is illustrated in Figure 3, and in essence defines the engineering problem to be solved.

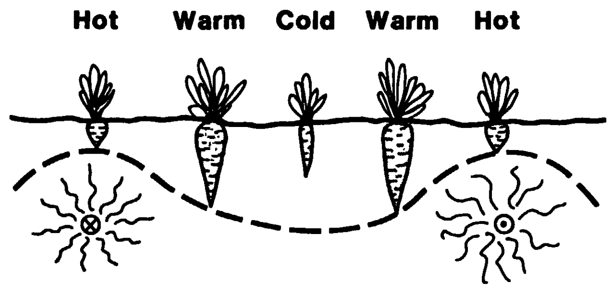

Figure 3. Idealized effect of temperature on carrots.

Thermal measurements were carried out in the first pipe-heated field at Fludir to characterize a typical soil heating system. The plastic pipes are buried at 70-80 cm depth and spaced at 180-200 cm. The length of each U-pipe is about 500 m (to-and-fro). The 93°C hot spring water cools to 36-44°C (depending on pipe), and is discharged into a nearby river as before. The thermal load remains constant over the summer and is about 20 W/m^2. Measurements in heated fields nearby showed 20-40 W/m^2. The growers reckon that 30 W/m^2 provide the most suitable heating. The pressure in the pipes is nowhere greater than 2 m water which explains why standard polyethylene pipes can be used. They are 40 mm (1-1/4") nominal diameter as commonly used in cold water service.

Typical temperature measurements for a day (24 hours) in early August are shown in Figure 4. The standard air temperature at 2 m above ground level was in the range 10-15°C which is on the warmer side for the Fludir area. The temperature at ground level (among the cabbage) was a little higher, but followed the same overall trend. Outside the heated field, the soil temperature at 20 cm depth was recorded close to 14°C; this seems rather high. In the heated field the soil temperature at 5 cm and 20 cm depths were close to 19°C and 23°C, respectively. These temperatures were measured above the hotter arm of a U-pipe, about 22 m from the inlet/outlet end of the field. These measurements show that the soil temperature is in the optimum range of 20-30°C for common vegetables.

Across the width of the field the soil temperature varies with the location of the hot and cold (warm) arms of the U-pipes. A temperature profile was measured at 20 cm depth (at 20 cm intervals) across the field 18.5 m from the inlet/outlet end of the pipes. The measurements are shown in Figure 5. They clearly demonstrate that optimum temperatures are achieved only above the hot arm of the U-pipe; the pipes are spaced too far apart for uniform temperature distribution.

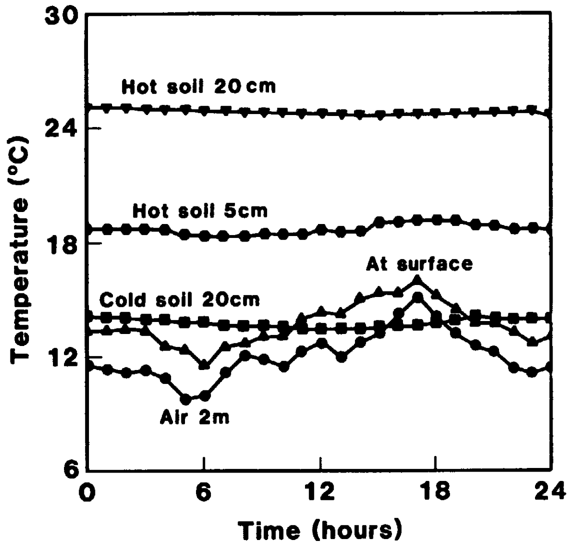

Figure 4. Temperatures measured in vegetable field at Fludir.

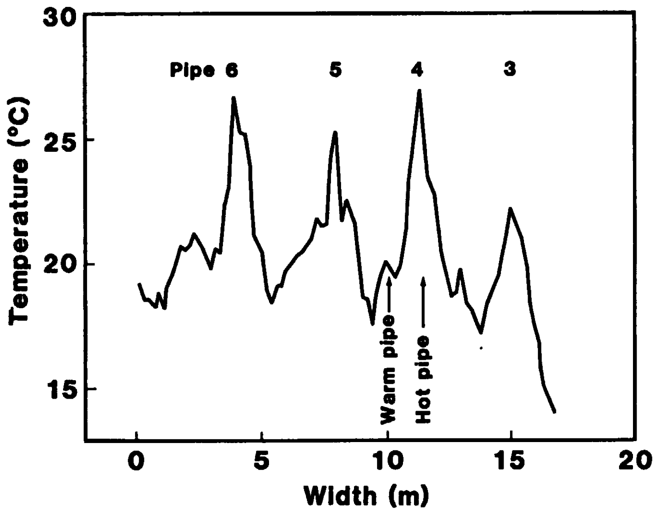

Figure 5. Temperature profile at 20 cm depth across field.

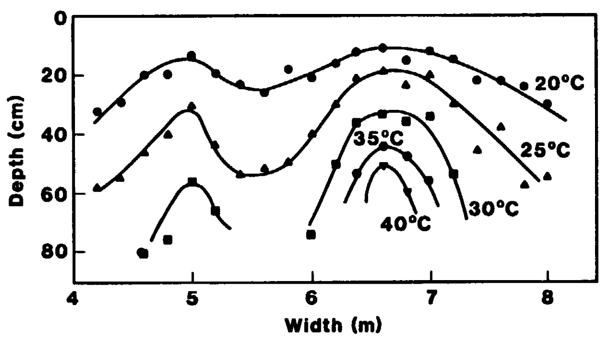

Figure 6. Temperature cross section around one U-pipe.

The soil temperature varies along the length of the field, parallel to the U-pipes. At the inlet/outlet end the temperature difference is the greatest while at the other end the temperatures are more uniform. A temperature cross section was measured above one U-pipe at about 80 m from the inlet/outlet end of the field. A 20x20 cm grid was used; Figure 6 shows the isotherms determined from the measurements.

DESIGN CORRELATIONS

It was recognized that design methods were required to aid in the development of geothermal soil heating systems in Iceland. Jonsson et al. (1982) have reported the main correlations that resulted from that work. The thermal problem was solved numerically for the geometry shown in Figure 2. The system was assumed steady state and two-dimensional; soil thermal conductivity and surface heat transfer coefficient were taken as constants.

It was determined convenient to use dimensionless parameters when deriving the design correlations; see nomenclature. The dimensionless heat flux from a U-pipe was found to depend on three other dimensionless parameters:

$$q^* = \frac{qD}{k(T_1 - T_\infty)} = f(Bi, \frac{L}{D}, \Theta_2)$$

A range of typical values was determined for each of the parameters based on previous experimental work. These typical values were then used to solve the governing heat transfer equation numerically. The next step was to obtain correlations of practical use for those designing geothermal soil heating systems.

A cross-correlation scheme was devised for this purpose. It was discovered that the dimensionless heat flux and mean temperature (at a given depth) were proportioned to $(1+\Theta_2)$. It was more difficult to find a suitable function to express q^* in terms of Bi and L/D because it was not possible to separate them as independent parameters. Therefore, the product (a+bL/D) ln (1+Bi) and a second degree polynomial in D/L were used. The best fit resulted in the correlation:

$$q^* = (1+\Theta_2)\left[(1+0.2\,\frac{L}{D})\ \ln\,(1+Bi)\right]^{0.2}$$

$$\left[0.056 + 0.483\,\frac{D}{L} - 0.215\,(\frac{D}{L})^2\right]$$

When this correlation was compared to the numerical results, the maximum error was 2.4% while 75% of the values were within a 1% error band. The correlation can be used with reasonable accuracy if the dimensionless parameters are in the following (typical) ranges:

$$0 \leq \Theta_2 \leq 1$$

$$1.2 \leq \frac{L}{D} \leq 4$$

$$2.5 \leq Bi \leq 10$$

The soil temperature was expressed in terms of a mean dimensionless temperature Θ_m. It refers to a given depth and requires one more parameter than does the dimensionless heat flux; the depth ratio x/D. The mean dimensionless temperature was found to be linear in x/D with Bi affecting the slope. Using the dummy variable z = $(\ln Bi)^{-0.2}$ the following correlation was obtained:

$$\Theta_m = (1+\Theta_2)\, z\, [3z - 2.4 + (7.2-6z)\frac{x}{D}]$$

$$[0.056 + 0.275\, \frac{D}{L} - 0.125\, (\frac{D}{L})^2]$$

When compared to the numerical results, the maximum error was 5%. The correlation can be used for the same range of parameters as shown above in addition to the following:

$$0.0 \leq \frac{x}{D} \leq 0.8$$

To evaluate the total heat flux for a soil heating system, it becomes necessary to consider the third dimension along the pipes. It appears reasonable to assume the water temperature decreases linearily in the pipes from inlet to outlet. This means that at any cross section perpendicular to the pipes, the sum of $T_1 + T_2 = T_{in} + T_{out}$. Therefore, for the geometry shown in Figure 2 using U-pipes, the heat flux and mean temperature are independent of the third or axial dimension. It means that only the inlet and outlet water temperatures have to be known to calculate the heat flux and mean temperature.

It may be useful to show by example how the correlations given above can be used in practical situations. Suppose there is a vegetable field 100 m long and 26 m wide to be heated using a 70°C geothermal water. The desired soil temperature at 20-30 cm depth is assumed to be 20-25°C. If the mean air temperature is taken as 10°C and the water discharge temperature T_{out} = 30°C, the dimensionless temperature Θ_2 = (30-10)/(70-10) = 0.33. By trial and error the required depth and spacing can be found. If the pipe depth is taken as 50 cm and the spacing as 130 cm, then L/D = 2.6 and 10 U-pipes are needed in the field. Taking the soil effective thermal conductivity k=1 W/m°C and the surface heat transfer coefficient h=10 W/m²°C, the Biot number becomes Bi=5.

The dimensionless heat flux is calculated q*=0.34 and the heat flux q=41 W/m². Since the area of the field is 2600 m² the total thermal power becomes 107 kW and the water requirement 0.64 kg/s (l/s) since it is cooled from 70°C to 30°C. The dimensionless mean temperatures at 20 cm and 30 cm depths (corresponding x/D are 20/50 and 30/50) give soil temperatures of 21°C and 24°C, respectively. These temperatures are conveniently within the specified range of 20-25°C for optimum field conditions.

CONCLUDING REMARKS

There are several aspects of geothermal soil heating in Iceland that have not been dealt with in this paper. The most important of these is probably the overall feasibility of commercial soil heating systems. The factors that would go into such an evaluation are both many and uncertain; the results may, therefore, not be very meaningful. However, the several growers already involved are in no doubt (neither is the writer) as shown by their actions; geothermal soil heating can be highly feasible. What has been attempted in this paper is to bring forth some of the factors that argue for expanding soil heating systems in Iceland; to further utilize the geothermal resources.

The thermal characteristics of soil heating systems have been described and simple design correlations developed. It has been indicated that in parallel to this work the effects of soil heating on common vegetables have been evaluated. This was done in the same field as the thermal measurements were carried out under commercial conditions. These trials have proved interesting and support the contention that soil heating can be highly beneficial in the growing of common vegetables. It is outside the scope of this paper to report these trials in detail. However, a mention of the overall results is warranted.

Cabbage was grown in heated and unheated fields at Fludir in 1980 and 1981. The plants were raised in the same manner, planted at the same time and grown under the same conditions, except for the heat. The grower harvested the cabbage as usual, using the same criteria for cutting the cabbage for market. In 1980, which was a warm summer, the cabbage grown in the heated field was ready for market about one week earlier than that from the cold field. The average weight of the cabbage was 5-10% greater in the heated field; not a very strong effect. In 1981, which was a cold summer, the results were very different, emphasizing the great variability of the climate. Two varieties were grown. They were planted at the same time but grew at different rates. The earlier variety produced 32% more from the heated field than from the unheated field, and was ready for market 16 days earlier. The corresponding numbers for the later variety were 51% and 11 days. The value of the produce from the heated field was 67% higher than the unheated for the early variety, and 60% for the late variety: these results stem from the supply-demand character of the fresh vegetable market.

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NOMENCLATURE

Bi	Biot number
D	Depth of pipes, m
f	Function
h	Surface heat transfer coefficient, $W/m^{2\,o}C$
k	Effective thermal conductivity, $W/m\,^oC$
L	Distance between pipes, m
q*	Dimensionless total heat flux
T_1	Temperature hot pipe, ^oC
T_2	Temperature cold pipe, ^oC
T_m	Mean temperature at given depth, ^oC
T_∞	Air temperature, ^oC
z	Variable
Θ_2	Dimensionless temperature, $(T_2-T_\infty)/(T_1-T_\infty)$
Θ_m	Dimensionless mean temperature, $(T_m-T_\infty)/(T_1-T_\infty)$

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