SOME RESULTS OF A STUDY INTO THE FEASIBILITY OF LOW TEMPERATURE GEOTHERMAL UTILISATION IN ZALA COUNTY HUNGARY

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ABSTRACT

The Hungarian Oil and Gas Company (MOL) has decided upon an ambitious programme of low to medium temperature geothermal development in Hungary. The programme, which has the principal objective of increasing the use of environmentally clean indigenous resources in Hungary, is designed on the cascaded energy use principle coupled with injection of the spent geothermal fluid back into the reservoir.

This paper describes the most important features of the first of three such planned geothermal developments. This first development is located in the county of Zala in western Hungary and combines electricity production with direct use in industry, the space heating of housing and provision of domestic hot tap water in the town of Zalaegerszeg, greenhouse heating and balneological use. All the spent geothermal water will be injected back into the reservoir with the twin aim of sustaining reservoir pressure whilst minimising ground water pollution.

In this presentation parallels and examples are drawn from the direct use of geothermal energy in Iceland. There direct use provides heating for more than 85% of all housing, and geothermal energy currently satisfies about 46% of all primary energy needs of the whole country.

The paper also endeavours to outline some of the environmental benefits that accrue from the use of low temperature geothermal energy and some of the pitfalls that can and must be avoided.

1. INTRODUCTION

The Hungarian Oil and Gas Company (MOL) has decided upon an ambitious programme of low to medium temperature geothermal development in Hungary. The programme, which has the principal objective of increasing the use of environmentally clean indigenous resources in Hungary, is designed on the cascaded energy use principle coupled with injection of the spent geothermal fluid back into the reservoir. For this MOL proposes to refurbish and use abandoned oil and gas exploration wells, which were drilled in the fifties and sixties.

This dissertation will only feature the proposed Andráshida development, which entails the harnessing of a production/injection well pair (wells A-1/A-4) or doublet.

The Andráshida-Nagylengyel geothermal area is located in the western part of Hungary in Zala county. The Andráshida-field is situated about 3 km north of the town Zalaegerszeg, the capital of the county. The city has a population of some 60.000 and is important as a food industry and transportation centre. The area is flat agricultural land dotted with small villages and individual farms.

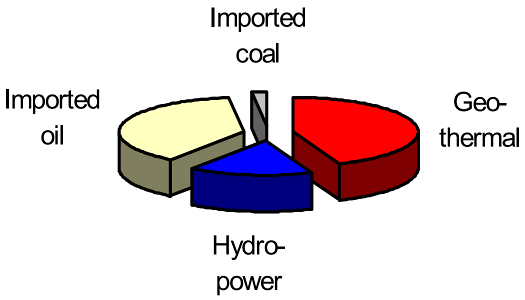
2. POTENTIAL BENEFITS OF GEOTHERMAL ENERGY

Geothermal energy sources, mostly low temperature ones, are bountiful in Hungary (see ref. 1, ref. 6 and ref. 8). Geothermal hot water has been harnessed for balneological purposes since Roman times (100-300 AC) and is today used for applications such as health-tourism, greenhouse heating (some 200.000 ha), pisciculture, house heating and in the supply of domestic hot tap water.

Being an indigenous energy source, it is a foreign currency earner through its ability to replace imports of for instance natural gas and fuel oils, which are the main competitors in its sphere of utilisation. Low temperature geothermal is environmentally very benign (ref. 6 and ref. 9), particularly when its use is coupled with injecting the spent fluid back into the reservoir. The environmental benefits can be very significant, bearing in mind that conventional house heating is one of the least efficient energy conversion applications of fossil fuel and highly polluting. To demonstrate the very great importance geothermal energy can play in a country's overall energy production scenario, the Icelandic situation will be summarised in the following chapter.

2.1 Importance of geothermal energy to Iceland

Iceland has the world's third highest per capita consumption of energy, or about 103.000 kWh (372 GJ) per year per head of population.



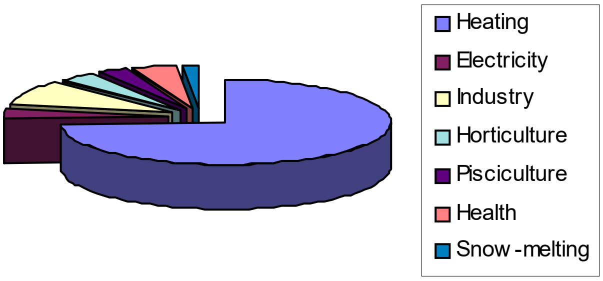
Primary energy use in Iceland

Geothermal energy provides 46% of the primary energy consumption in Iceland, hydro-power 16%, imported oil 36% and imported coal 2%. Thus 60% of the total primary energy is supplied from indigenous sources. Fossil fuel is used almost exclusively for motive power in the transportation sector and the large fishing fleet. This division is depicted in the pie chart.

The economically exploitable part of the geothermal energy resource is difficult to estimate accurately, but it is clear that only a small part of the geothermal energy resource has been tapped so far.

Geothermal energy has a multitude of useful applications in Iceland, the most important of which are:

1. Space heating (73,8%).
2. Electricity production (4,3%).
3. Industrial use (9,1%).
4. Horticulture (3,8%).
5. Pisciculture (2,8%).
6. Health uses (4,5%).
7. Snow melting (1,7%).



Geothermal energy uses

The relative importance of these is illustrated in the chart. It can be seen that space heating is by far the most important use of geothermal in Iceland, about 85% of all working and living space being heated that way. Geothermal hot water and steam are moreover used in many novel ways in industry, typically on a small scale.

The financial benefits of geothermal space heating alone as regards the import of fossil fuel comprises an annual saving of some 100 million US dollars. Environmental benefits are enormous. Currently there are some 30 municipal district heating systems, or "hitaveitas", operating in Iceland serving about 218 thousand people. The world's largest "hitaveita" is the Reykjavík District Heating Service, serving some 145 thousand people or more than half the population. In addition to the municipal ones, there are over 200 geothermal heating systems serving individual farms, groups of farms and/or clusters of summer cabins found throughout the country. They serve in total some 4 thousand people.

3. THE ANDRÁSHIDA DEVELOPMENT

A prerequisite to any proposed commercial development of a geothermal resource is a study into the aspects outlined in this chapter. MOL, prudently, adopted this strategy for the proposed Andráshida development. The yield of the Andráshida doublet is considered to be 30 l/s of 90°to 95°C water.

3.1 The fluid chemistry

In this chapter the effects of non-condensable gases in the fluid, and the scaling potential of the fluid are discussed.

Table 3.1.1 Typical chemical composition of water from well A-1

Chemical component	***Chemical content*** mg/l
Sodium (Na^+)	1,21
Calcium (Ca^{++})	66,11
Magnesium (Mg^{++})	9,55
Ammonium (NH_4^+)	4,34
Ferrum (Fe^{++}) +(Al^{+++})	1,75
Chlorides (Cl^-)	6,25
Hydrocarbonates (HCO_3^-)	193,02
Organic anions	7,63
Sulphates (SO_4^{--})	40,60
Bromide (Br^-)	0,60
Iodine (J^-)	0,00
HBO_2	3,69
H_2SiO_3	97,50
Total dissolved solids (TDS)	**432,25**
Other chemical features	
pH	8,00
Alkalinity (mg eq/l)	3,28
Total hardness (CaO g/m)	114,69
Variable hardness (CaO g/m)	88,60
Permanent hardness (CaO g/m)	26,00

Table 3.1.1 gives a typical chemical composition of the Andráshida geothermal fluid as obtained by measurement in well A-1. The fluid has a very low salinity but is fairly rich in calcium and hydrocarbonates. This indicates that careful water treatment is needed to prevent calcite scaling.

The chemical composition of the gas phase in the well A-1 fluid is given in Table 3.1.2. The gas/water ratio (GWR) measured 0,3 m3/m3. These data have been used in the following for interpretation and geochemical modelling. The purpose of which is to evaluate scaling characteristics, in particular calcite scaling, and also to give some preliminary plant design premises. The WATCH programme was used, being well established in the geothermal industry.

In the modelling, the composition of the water and gas sample is entered as input to the programme along with the GWR (gas-water ratio) value. The programme then calculates the downhole component composition and species concentration, as well as ionic activity products and solubility products for various minerals. With this information in hand the effect of the cooling in the utilisation process can be calculated.

To evaluate the calcite scaling potential, the ionic activity product "Q" for the fluid is calculated at the prevailing well head temperature and then at several lower temperatures assuming conductive cooling e.g. in a pipeline or a heat exchanger. The results are compared with the theoretical solubility product constant "K" and the saturation index (SI) evaluated:

$$SI = \log(Q/K)$$

If the saturation index is greater than zero (0) the water is super-saturated with respect to calcite and mineral deposition (scaling) may occur. On the other hand the water is in equilibrium at SI=0, and for SI<0 the water is under-saturated. Experience from Iceland has shown that the scaling is most pronounced above a SI value of 0,5.

The calculations show high super-saturation at well-head temperature of 90°C (Fig. 3.1.1), if the water is wholly de-gassed. Subsequent cooling of the water in a closed system shows, that the water is at all temperatures within the super-saturated region and above the log(Q/K) value of 0,5. This indicates heavy calcite scaling potential of the water phase at all temperatures. The story is quite different if degassing of the geothermal fluid is prevented by pressurising the fluid. The results indicate the water to be slightly super-saturated at a temperature of 90°C, but it soon becomes under-saturated upon cooling (Fig. 3.1.1).

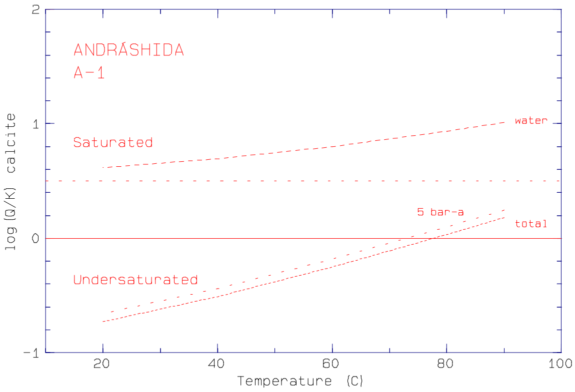


Figure 3.1.1 Calcite scaling potential in fluid from A-1

Degassing the water to 5 bar-a releases carbon dioxide from the fluid and increases the pH slightly. This degassing raises the SI value by a small amount as indicated by the 5 bar-a curve in Fig. 3.1.1. It is still, however, well within the saturation range where no serious calcite scaling has been observed according to the experience in Iceland.

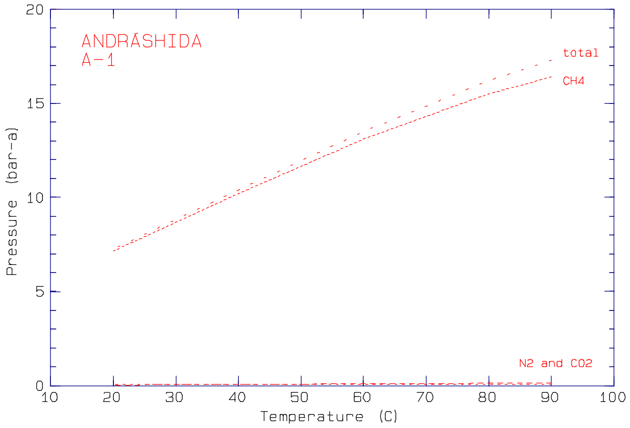


Figure 3.1.2 Effect of temperature on the partial pressure in Andráshida fluid

Table 3.1.2 The chemical composition of the gas in well A-1

Gas component	***Concentration vol %***
CH_4	86,79
N_2	0,21
CO_2	12,18

The partial pressures of gases in the liquid phase are influenced by the temperature of the water. The results for well A-1 are shown in Figure 3.1.2. The calculations indicate a total gas-pressure (bubble point) of the geothermal fluid to be 17,3 bar-a. The calculations demonstrate that methane (CH_4) is responsible for this high gas pressures, due to its high concentration and its insolubility in water. The partial pressure of nitrogen (N_2) and carbon dioxide (CO_2) are well within 0,1 bar-a at all temperatures.

Some preliminary calculations have been made to estimate the amount of gas (% by volume) released from the geothermal fluid at different pressures for the Andráshida area. In the calculations it is assumed that nitrogen (N_2) and methane (CH_4) will be the main free gas components.

The results are depicted on Figure 3.1.3. On the figure the volumetric percentage of gas (N_2 + CH_4) at a given pressure, has been plotted against the separation pressure for two temperature values,

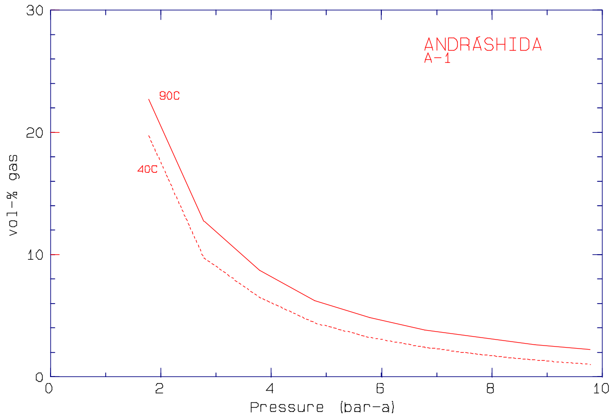


Figure 3.1.3 Gas release from the Andráshida fluid

i.e. the assumed well-head temperature of 90°C and then as the fluid has cooled to 40°C. The calculations indicate that approximately 5% per volume of gas may be present in the geothermal water at a well head pressure of 5 bar-a and a well head temperature of 90°C.

3.2 Re-injection of spent fluid

The long-term production potential of well A-1 is controlled by the permeability and areal extent of the reservoir as well as the natural recharge to the reservoir. These factors are largely unknown, except for some limited knowledge about the permeability of the reservoir rocks, which is in the range of 0,01 to 10 Darcy.

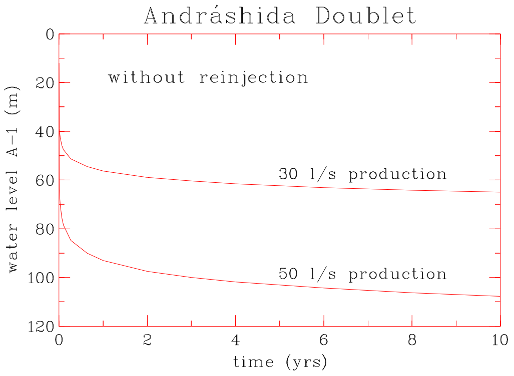


Figure 3.2.1 Long-term draw-down in the Andráshida reservoir

The long term draw-down is estimated by assuming a permeability of 0,1 Darcy, slightly higher than the minimum permeability mentioned above. The reservoir thickness is assumed to be 200 m. The results of these calculations are presented in Figure 3.2.1. This figure shows the estimated draw-down in the well for two production scenarios (30 and 50 l/s), for a period of ten years. Some turbulence losses are also assumed. The very limited, and uncertain, data dictates that it be only considered a rough idea on the behaviour of the well during long-term production. The actual long-term draw-down will likely be smaller. This rough estimate shows a draw-down of less than 70 m and less than 110 m for long-term production rates of 30 l/s and 50 l/s respectively. The well will, however most likely only sustain a production rate of 30 l/s.

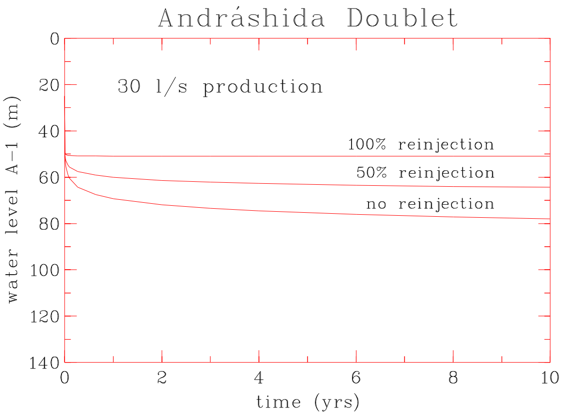


Figure 3.2.2 Effects of re-injection on reservoir draw-down

Re-injection into well A-4 will counteract the long-term draw-down (see Fig. 3.2.2). Re-injection into karstic carbonate rocks has proved to be successful in Hungary and other parts of the world (see ref. 2. and ref. 5).

3.3 Potential thermal break-through

Re-injection in Andráshida may face two difficulties. One is a possible thermal break-through into well A-1. Assuming a reservoir thickness of 200 m, and a porosity of 1%, the following thermal break-through times have been estimated for different rates of re-injection:

Table 3.3.1 Estimated thermal break-through time

Injection rate (l/s)	*Break-through time (yrs)*
10	170
30	60
50	35

Table 3.3.1 shows, however, that thermal break-through is unlikely to be a problem in the near future. Channelling of the flow between the wells cannot be ruled out without further testing. A consequence of channelling is that very much shorter thermal break-through times may be expected.

The other difficulty concerns the question whether well A-4 will be able to accept the planned rate of re-injection (30 l/s or more). Assuming that long-term re-injection into well A-4 will be possible, the assumptions used above (permeability, thickness and porosity) were again used to estimate the benefits of re-injection on the water level in well A-1 during long-term production/re-injection. The results are presented in Figure 3.2.2.

3.4 Proposed utilisation scenario

Survey of heat consumers in Zalaegerszeg was done both for communal and industrial circles. All the consumers, were found to be suitable for geothermal heating, were grouped into four (4) so called districts of consumers, namely Vorhota, Landorhegy, Kertváros and Balatoni. Each of them was investigated technically and, according to a special pre-selection one (1), that is Landorhegy was applied for the financial assessment. As an alternative solution for utilising the thermal energy from geothermal a four (4) hectare area new greenhouse plant was supposed to be built in the vicinity of the Andráshida Doublet. The cascaded connection of Landorhegy and a two (2) hectare area greenhouse plant was also investigated as a possible future utilisation.

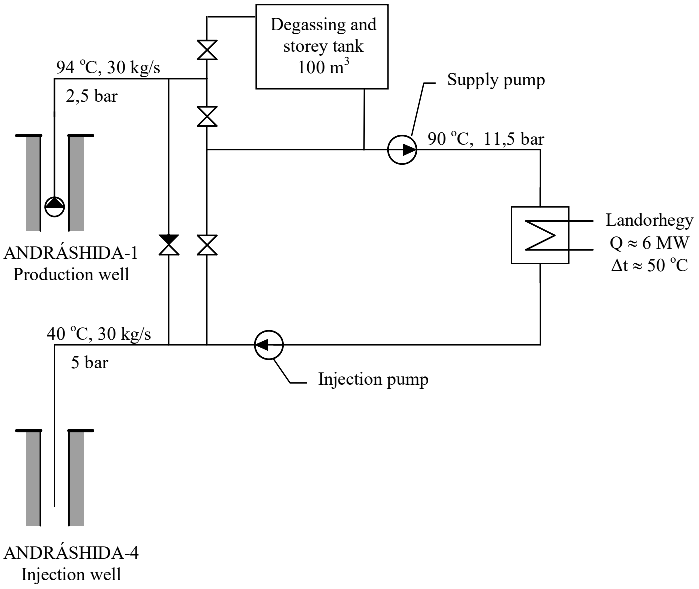


Fig. 3.4.1 Process diagram for the Landorhegy development

Features of the Landorhegy development

Process diagram for the Landorhegy development is shown on Fig. 3.4.1
Prior to selecting the production process it is important, in addition to the permanent draw-down, to estimate the fluid temperature at the well-head. The cooling that takes place as the fluid flows up the well was estimated for different flow rates and the results are summarised in Fig. 3.4.2.

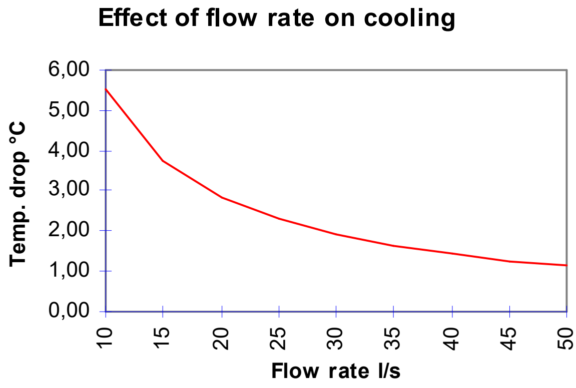


Fig. 3.4.2 Cooling of the geothermal fluid up well A-1

Geothermal water is degassed from gas content in a 100 m^3 water tank, and forwarded to the site of the utilisation. The geothermal station and Landorhegy area is connected by a 200 mm diameter trans-mission pipeline. The approximate length of the pipe route is 7,2 km. Size of the distribution network's pipes varies between 50 mm and 150 mm at a total length of 6,9 km.

In the Landorhegy housing estate, which is actually the largest one in the city, some 43 sub-stations are going to be supplied by geothermal. Heat transfer is solved by using of plane type of heat exchangers. Peak heat demand can, therefore, be provided by the existing boiler stations.

Return pipeline is supposed to be not heat insulated in order to reduce the cost of investment. Cooled geothermal water is injected back to the reservoir through the well A-4. Injection pumps are located in the geothermal station.

Financial assessment

Geothermal energy available for the replacement of natural gas was calculated thoroughly. So called duration diagram was carried out for all the three (3) alternatives , i.e. Landorhegy, New Greenhouse Complex and the cascaded use of them. Duration diagram for the Landorhegy development unit is shown on Fig. 3.4.3.

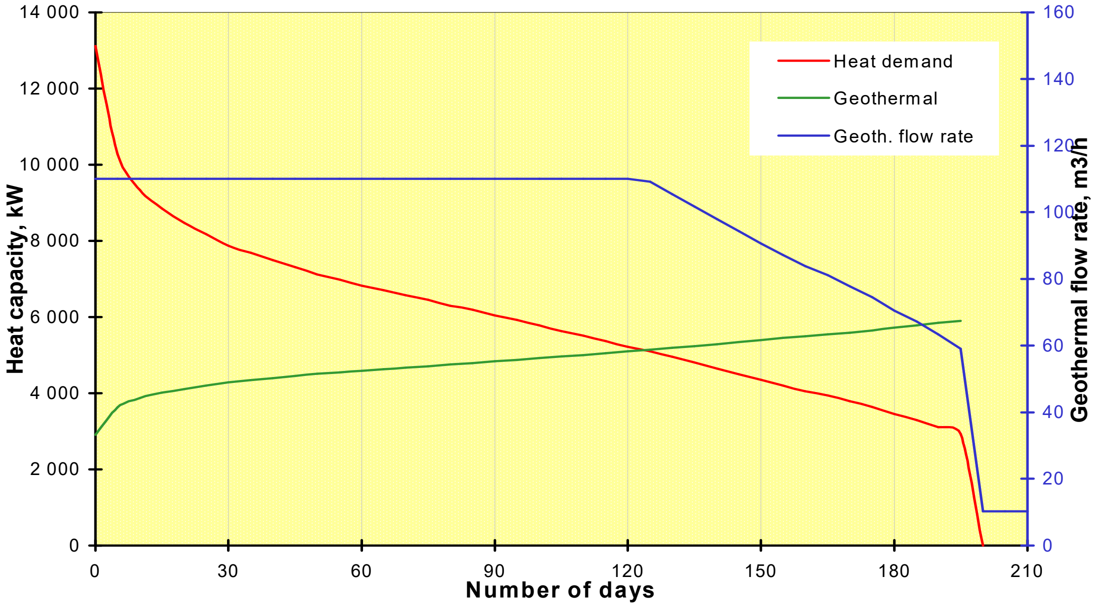


Fig. 3.4.3 Duration diagram of Landorhegy development unit

Results of the calculations:

Annual geothermal energy available to sell:	96 353 GJ
Annual earning:	471.000 USD
Investment cost	2.618.357 USD
Annual operating cost:	100.079 USD

Financial viability analysis of the proposed development adopts MOL Co.'s stipulated twenty-five (25) year depreciation and nine (9%) per cent discount rate on the investment for the net present value calculation. The outcome of cash flow analysis is presented as follows:

Net present value	905.054 USD
Pay back period	7,13 years
Internal rate of return	13,4%

The above calculations albeit somewhat approximate, in that they do not take into account effects of re-payment schedule and grace period, etc., demonstrate an acceptable potential profitability of this investment. It must, however be pointed out that the profitability potential depends upon the cost and success of the reconstruction works needed on the wells.

4. LOW TEMPERATURE GEOTHERMAL AND THE ENVIRONMENT

Atmospheric pollution knows no geographical boundaries. Its effects are both local and global. Hungary has, in recognition of this fact, undertaken international obligations to reduce such emissions. International and national concern about climatic changes, acid rain and the so called "greenhouse effects" compel Hungary like most of the international community to cut carbon dioxide emissions. The Hungarian authorities therefore give high priority to the harnessing of environmentally benign alternative energy sources of non-fossil origin. The harnessing of indigenous energy sources, such as geothermal energy, is given high significance in the national energy policy and regional development.

Deleterious environmental effects associated with low temperature (fluid temperatures at 1 km depth below 150°C) geothermal energy are typically quite insignificant. This is particularly the case at temperatures below 90°C (see ref. 9).

Nitrogen oxide, carbon monoxide and carbon dioxide are the important pollutants in Zala county, natural gas being virtually the sole primary energy source for thermal energy production.

In certain localities pollution of ground water is possible from the surface discharge of geothermal effluents containing traces of such elements as mercury (Hg), boron (Bo) and fluoride (F). Some of these may cause danger to health. This is not relevant in the Andráshida area, where full (100%) re-injection will be employed.

Table 4.1 summarises the current total and residential air pollution in the town of Zalaegerszeg as well as the reduction attainable through the use of geothermal energy, both in absolute and percentage terms. The table moreover shows, that air pollution in the town would drop substantially as a result of the proposed geothermal energy development, particularly that due to carbon oxides (CO and CO_2).

5. CONCLUSIONS

The study carried out for the Andráshida doublet permits the following conclusions, albeit based upon limited reservoir and chemical data:

- The technical feasibility of producing electricity via binary energy converters at the prevalent low primary temperature (90°to 95°C) is extremely marginal. It is not economically viable.
- The estimated long term (10 year) draw-down at a production rate of 30 l/s without re-injection is forecast to be just under 70 m relative to the well-head flange. With full (100%) re-injection of the spent fluid at this rate the draw-down is reduced to about 50 m.
- Thermal break-through into well A-1 may take some sixty (60) years, unless channelling occurs. Cooling of the well fluid en route to the surface is about 2°C at the envisaged 30 l/s production rate.

Table 4.1 Potential atmospheric pollution avoidance from the proposed Andráshida geothermal development

Type of pollution	*Pollution rate (Mkg/year)*		*Achievable pollution reduction*		
	Total	*Residential*	*(tonne/year)*	*Relative to total*	*Relative to resid.*
NO_x	0,38	0,04	4,4	1,2%	11,0%
CO	0,99	0,09	41,2	4,2%	45,8%
CO_2	78,2	32,6	7.806	10,0%	23,9%

- The produced fluid has a high calcite scaling potential, if fully degassed before use. Partial degassing at 4 to 5 bar absolute pressure largely avoids this problem. Gas in the primary system fluid requires careful system design to avoid gas pockets and reduces somewhat heat exchanger performance.
- The direct utilisation of geothermal energy in Zalaegerszeg is quite competitive with natural gas in price whilst complying with acceptable economic viability criteria. The heating market, though somewhat distant from the geothermal field (6 to 8 km), is large, concentrated and positive towards geothermal.

- The potential reduction in carbon oxide emissions from this one geothermal developments amounts to some 7.850 tonnes per annum.

It is recommended that comprehensive flow testing, careful chemical modelling and interference testing be carried out prior to project implementation.

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