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UTILIZATION OF GEOTHERMAL ENERGY

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ABSTRACT

The use of geothermal heat for the generation of electricity is very popular, as there is a ready market. Most of the power is produced in turbines by flash-steam. By making vapour from low boiling point fluids in a secondary loop, additional electricity can be generated. Other uses are mainly for recreational bathing and space heating in cold climates. Industrial steam can be supplied, as geothermal steam is pure water vapour with only a small amount of carbon dioxide gas. Conventional process equipment can be used with only minor modifications. All of these uses have to take place close to the geothermal resource. The main obstacles to direct uses are that the steam is not sold as a utility, the remoteness of the geothermal sites, the reluctance to zone industrial areas in places of natural beauty, and the steam not being a major cost item in most industries. Processing of agricultural products and natural materials are most likely to benefit from the direct use of geothermal heat. Small industries may also benefit. These industrial users should be given access to high grade steam parallel to power generation, rather than to waste heat only. Possibly, the tourist and spa industry might use the waste heat. There are thus a multitude of potential direct use applications where geothermal heat can play a role in Africa. Based the on experience from other geothermal regions around the world, however, the interest in using geothermal energy for other than electricity generation will likely be small.

1. INTRODUCTION

For millennia hot water has been used for bathing and some cooking of food. An Englishman by the name of Campbell in a travel book described his vision for the use of geothermal energy after a visit to Iceland way back in 1865. “If Icelanders would use hot springs which have worked for centuries, they might have winter-gardens and hothouses; they might boil their mutton for nothing and sell the soup; they might at least warm their houses and cow-byres, irrigate their hay-fields, and wash in the hot water which runs to waste at their doors“.

Electricity was first produced a century ago with geothermal steam and has now been harnessed on a large scale for almost half a century in many countries. Geothermal heat is used for space heating in cold climates and for baths and recreation wherever there is a source of hot water.

The generation of electricity is the favoured application of geothermal energy as in many countries there is not a natural market for hot water. A large quantity of hot wastewater comes from these plants that could be used for heating and other purposes. There are two co-generation plants in Iceland that use the wastewater from electricity generation for heating of freshwater for district heating. In these plants, the heating market is nevertheless not able to make use of all the wastewater. More commonly, however, the water used for district heating systems originates from low temperature wells.

Geothermal fluids are not only a source of energy as they also contain gases and dissolved solids which can be extracted in commercial quantities. In the past, boron in Italy, salt in Iceland, and zinc in USA were produced but now there is only the production of liquid carbon dioxide in Iceland and Turkey.

The liquid carbon dioxide is used for the soft drink industry, for making dry ice for the food industry, and for enrichment of the atmosphere of greenhouses. There are thus a multitude of possibilities that can be considered when a new geothermal resource is being opened up. All of these direct uses have to take place locally as it is only practical to send the steam some 2 km and the hot water perhaps 20 km. Electricity on the other hand can be transported to distant markets. Possibilities for local economic development exist in many places, but have seldom been taken advantage of in the past. Most of these direct applications are for using thermal energy on a small scale, at least relative to typical well outputs.

Most of the geothermal literature has to do with the geosciences and exploitation of the reservoir. Less has been published on direct uses, except for space heating and balneology. Sources for additional information on direct use are: “Geothermal Direct-Use Engineering and Design Guidebook” (Geo-Heat Center, 1998) and “Lectures on Direct Utilization of Geothermal Energy” (Lund, 1996), the annual conference proceedings of the Geothermal Resources Council (GRC) and at Stanford University, and the on-line library database of GRC (http://www.geothermal.org /nsearch.php?Cid=3). The yearbook of the United Nations University Geothermal Training Programme publishes the papers by fellows and the special lectures. These are also found on the UNU website (http://www.os.is/page/unugtp) under “Yearbook”.

Quite a number of industrial applications have been tried in the past, but the picture is not very encouraging as many have gone out of business after a few years. There are several explanations for the low interest shown in the industrial applications. The remoteness of the resource, no one selling steam as a utility service, the image that it is worse than boiler steam, are partly to blame, but also there are few industries where the cost of heat is a major one. This paper will nevertheless briefly describe where the direct use possibilities lie, as some of these could be of interest in Africa. The argument is made that the most feasible options will be found where electric power plants will be built and where steam only would be used. This is the very same steam as could be used by the turbines because then there are very few technical problems and conventional industrial steam equipment is suitable. Cascaded use of the thermal resource to extract the waste heat is also a possibility, but with more technical problems due to scaling and limitations as to what can be processed at low temperatures. The tourist and spa industries may be the most likely sectors to benefit from the use of waste heat.

2. THE STATISTICS

At present (2005), the installed geothermal electrical generating capacity in 24 countries is 8,900 MW_e. There are 468 turbines, generating 57,000 GWh per year (Bertani, 2005). Statistical information on the electrical sector is published annually by the Japanese Geothermal Energy Association (JGEA) and compiled at five year intervals for the large international geothermal conferences the World Geothermal Congress (last 2005 Turkey) and is also published by the International Geothermal Association (IGA) on the Internet.

When this kind of data appears as ton oil equivalent TOE of "primary energy" in the Eurostat or the World Energy Council reports (WEC), it is based on 10% energy recovery for electricity generation. This method of reporting gives a rather inflated picture of geothermal as compared to other renewable sources such as hydro and solar where only the net power generated is tabulated as primary energy.

Non-electrical direct use data is not easy to compile due to the many and varied uses. Furthermore, the methods of computing the power and energy use have changed over time. Every time one views the statistics, examine the basis of calculation, especially the reject or base temperature, which can be either 40°C, 35°C, the average ambient temperature, or 0°C. The International Geothermal Association (IGA) has in 1998 published "Standardized reporting on direct geothermal energy use statistics" in an attempt to unify the method of computation. The report states: "*Primary energy* is defined as energy in its naturally occurring form before conversion, transmission and distribution to end-use forms and *Final energy* is defined as the total energy consumed by end-users. It does not include losses in generation, transmission and distribution of energy, or losses in energy production plants. This is suitable for comparing energy consumption in different utilisation sectors". The recommendation of IGA is that reporting should be made for "Final energy" where:

Energy use (TJ/yr) = Average flow rate (kg/s) x [inlet temperature (°C) – outlet temperature (°C)] x 0.1319

and

Capacity (MWt) = Maximum flow rate (kg/s) x [inlet temperature (°C) – outlet temperature (°C)] x 0.004184

The predominant direct use is in Japan for "onsen" (balneology) in Iceland for "hitaveita" (geothermal district heating system), and in China for aquaculture. The WGC statistics show the present installed power for direct use to be 27,825 MW_t and energy 72,622 GWh/yr (Lund, Freeston, and Boyd, 2005).

3. THE RESOURCE

High temperature geothermal resources with temperatures greater than 150°C are more suitable for industrial applications, as then there is the possibility of supplying industrial grade steam. For many processes, steam is the preferred heat transfer medium at 5 bar (159°C) or 10 bar pressure (184°C). Steam at these pressures is, however, also sought after for power generation. The important thing to remember is that steam turbines consume a lot of steam or 1.8-2.2 kg/s for every MW_e of electricity generated. A large industrial plant may only use 10 kg/s in total, like the diatomite factory in Iceland did. Even a large user of steam will thus normally only consume a very small fraction of what a power plant needs. Power companies can thus allow parallel uses of steam in their fields without much sacrifice. Also for reasons of small size it is difficult to envisage industrial steam users to pay alone for the field development in a new geothermal area. The industrial steam users are likely to ask for the steam at unrealistically low prices.

The greatest advantage would be where steam is not required but where hot waste water could be used, for example 150-180°C brine from the steam separators. These applications are, however, likely to lower the fluid temperature into the region where scaling becomes a problem. The extra cost in treating that problem means that such users can not be expected to pay much for the waste water. This is referred to as cascaded use, when a series of users can harness energy from what the earlier process sends out as waste.

One thing to remember is that by setting the requirements high for industrial steam pressure relative to the reservoir temperature, not all reservoirs will be able to deliver it and the steam fraction will be small in any case. Based on an example from Iceland: if one wants to produce retread tires for cars one needs 150°C for the curing of the rubber and the minimum steam pressure is 6 bar. This pressure could for example not be supplied from a 180°C well as the wellhead pressure may only be 5 bar and the steam fraction small.

4. THE CONCEPT OF A RESOURCE PARK

Power plants, once built, require relatively few but a highly qualified staff. The typical number of operation and maintenance staff at a geothermal plant ranges from 0.5-2 persons per MW_e. The non-power industries that would be allowed to tap into the geothermal resource could employ a lot more people. One company in Iceland, Sudurnes Regional Heating, has developed the concept of a Resource Park for their field at Svartsengi.

The Resource Park idea is to generate as many revenue streams from geothermal utilisation as possible. This has been very successful and is a case history of what can be achieved. The resource there is a brine of 2/3 salinity compared to seawater having a temperature of 240°C. First is a so called co-generation power plant that supplies 45 MW_e of electricity and 150 MW_t of hot water for a district heating system. Half the waste brine goes to surface disposal in a lava field where the brine forms a lagoon (Blue Lagoon) and finally infiltrates into the ground. The other half (130 l/s) is reinjected at

110°C together with all the condensate. The Blue Lagoon is a magnet for tourists, local and foreign, drawing over 300,000 thousand guests annually to bath in the bluish-white water in the spa complex. Hardly a tourist comes to the county without a visit to the Blue Lagoon. A line of skin care products is selling briskly incorporating the silica sludge and algae. The therapeutic nature of the water helps people with the skin disease psoriasis and a separate treatment centre has been set up for that. Then there is a geothermal exhibition at the power plant, highlighting volcanism and the resulting geothermal energy and a conference centre. Restaurants plus a hotel to cater to the tourists and expansion of the spa complex is under way, with hotels also being a part of the plans. These activities employ more people than the power plant itself, and put all together the geothermal resource at Svartsengi is of significant economic benefit to the communities on the Reykjanes peninsula.

5. GENERATION OF ELECTRICITY

Turbines are used for power generation from geothermal energy and for these there are several alternatives: single flash (back pressure or condensing), double flash (condensing), and binary (organic Rankin cycle, ammonia-water). Single flash steam is made by reducing the fluid pressure to a set value, say 5-10 bar, and separating the steam from the water. A double flash steam is produced when this process is repeated again.

Most of the geothermal electricity in the world is generated with flash steam. The turbine steam pressure is usually determined by the minimum pressure at which the well fluid can be flashed without the risk of silica scaling. If a second flash is made, it increases the amount of power than can be generated, but usually takes the fluid into the region where silica forms scales, affecting the life of reinjection wells. Now that the requirement in most countries is to reinject the brine, such double flash plants have lost popularity. Most plants now are single flash.

The geothermal steam turbines are manufactured mainly by three Japanese companies, but Italian, US and Russian companies have also produced such units. The unit size has grown over the years and is now in the range 30-50 MW_e as these can be assembled fully in the factory and transported in sections to the site. How big the section that can be transported, is thus one of the deciding factors for the turbine size. Most plants nowadays are delivered as “turn-key”. The total cost is in the range 1.5-2.0 million US$ per MW_e for conventional plants, the cost of production and reinjection wells not included.

It is possible to generate power from low grade heat in co called binary units where the geothermal fluid is used to make vapour from a low boiling point fluid. Two working fluids have seen commercial application, isopentane and ammonia-water mixture. This vapour subsequently drives a turbine or is passed thorough an expander to generate electricity in a closed loop. Early binary units were small (1.3 MW_e) but are at present made in unit sizes up to 10 MW_e, with 17 MW_e units on the horizon. These Organic Rankin Cycle (ORC) plants mainly use isopentane as the working fluid and cost some 2-2.5 million US$ per MW_e, not counting the wells. Most of the binary units have been made in Israel but there are just a few Italian, American, and Russian units. An Icelandic company has recently entered the market. In the past, a great number of small binary units were placed side by side to generate the required amount of power. Now these modular units have outgrown the 40 ft. shipping container format. Factory assembly and quick erection on site are still one of the features. There is now interest in installing such units at existing geothermal plants and using the wastewater from the separators in what is termed a “bottoming” plant. These units pass the water through a heat exchanger before it goes to the reinjection well. The additional cooling will normally cause silica scaling in the heat-exchangers and downstream pipes. To counteract the scaling problem acidification to lower the pH to 5-5.5 is called for. Figure 1 shows roughly the required flow or water to produce 1 MW_e of power, as a function of the brine inlet temperature.

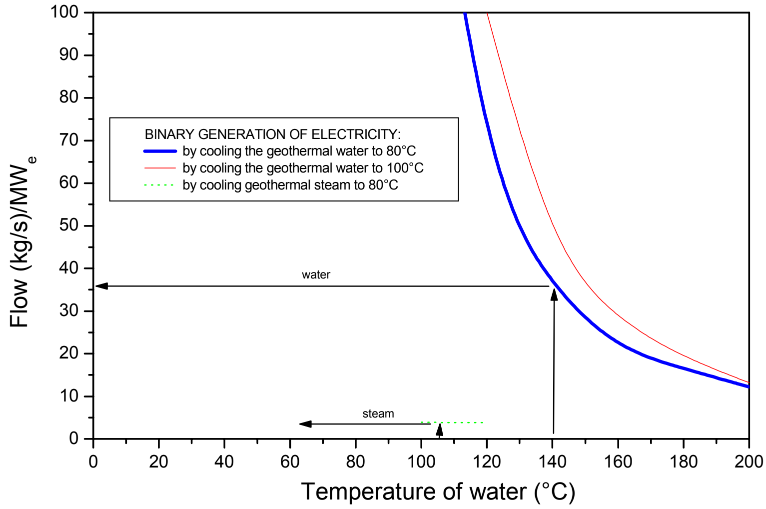

FIGURE 1: The approximate flow required to generate electric power with binary units, as a function takes a flow of 35 l/s.of the geothermal fluid temperature. For example to generate 1 MW_e from 140°C water,

6. INDUSTIAL USES

Industrial uses of geothermal heat have not gained popularity for various reasons, in spite of a fair amount of promotion in the last 25 years. Iceland has had access to geothermal heat for a long time, but now there are only a limited number of industrial users. It is at present used for drying seaweed, some drying of fish and as washing water in the food industry. In spite of the proximity of geothermal sites to the food growing regions of California, there is only one plant drying garlic onions in Nevada. In New Zealand, there is a factory that dries lucerne for animal feed and a paper factory that gets a part of its steam from geothermal. Grain drying is found in Serbia and coconut drying in the Philippines.

Several reports have been written in the past to identify sectors where geothermal heat could play a role. Such studies have been made by Lindal (1993), Reistad (1975), Howard (1975 and Lienau (1991). A list is shown below is from a World Bank webpage (www.worldbank.org /html/fpd/energy/geothermal/index.htm) and Figure 2 shows a greater number of possibilities (Lund J. et al 1998).

180°C Evaporation of highly concentrated solutions, Refrigeration by ammonia absorption
Digestion in paper pulp (Kraft)
170°C Heavy water via hydrogen sulphide process. Drying of diatomaceous earth.
160°C Drying of fish meal. Drying of timber.
150°C Alumina via Bayer's process.
140°C Drying farm products at high rates. Canning of food.
130°C Evaporation in sugar refining. Extraction of salts by evaporation and crystallization.
Fresh water by distillation.
120°C Most multi-effect evaporation. Concentration of saline solution.
110°C Drying and curing of light aggregate cement slabs.
100°C Drying of organic materials. Seaweed, grass. vegetables etc. Washing and drying of wool.
90°C Drying of stock fish. Intense de-icing operations.
80°C Space-heating (buildings and greenhouses).
70°C Refrigeration(lower temperature limit)
60°C Animal husbandry. Greenhouses by combined space and hotbed heating
50°C Mushroom growing. Balneology.
40°C Soil warming Swimming pools, biodegradation. Fermentations.
30°C Warm water for year-round mining in cold climates. De-icing. Hatching of fish.
20°C Fish farming.

Most of these applications have at one time or other been realized in Iceland, except the ones shown for 180°C, heavy water, drying of fish meal, alumina, canning, fresh water distillation, sugar refining and refrigeration at 70°C.

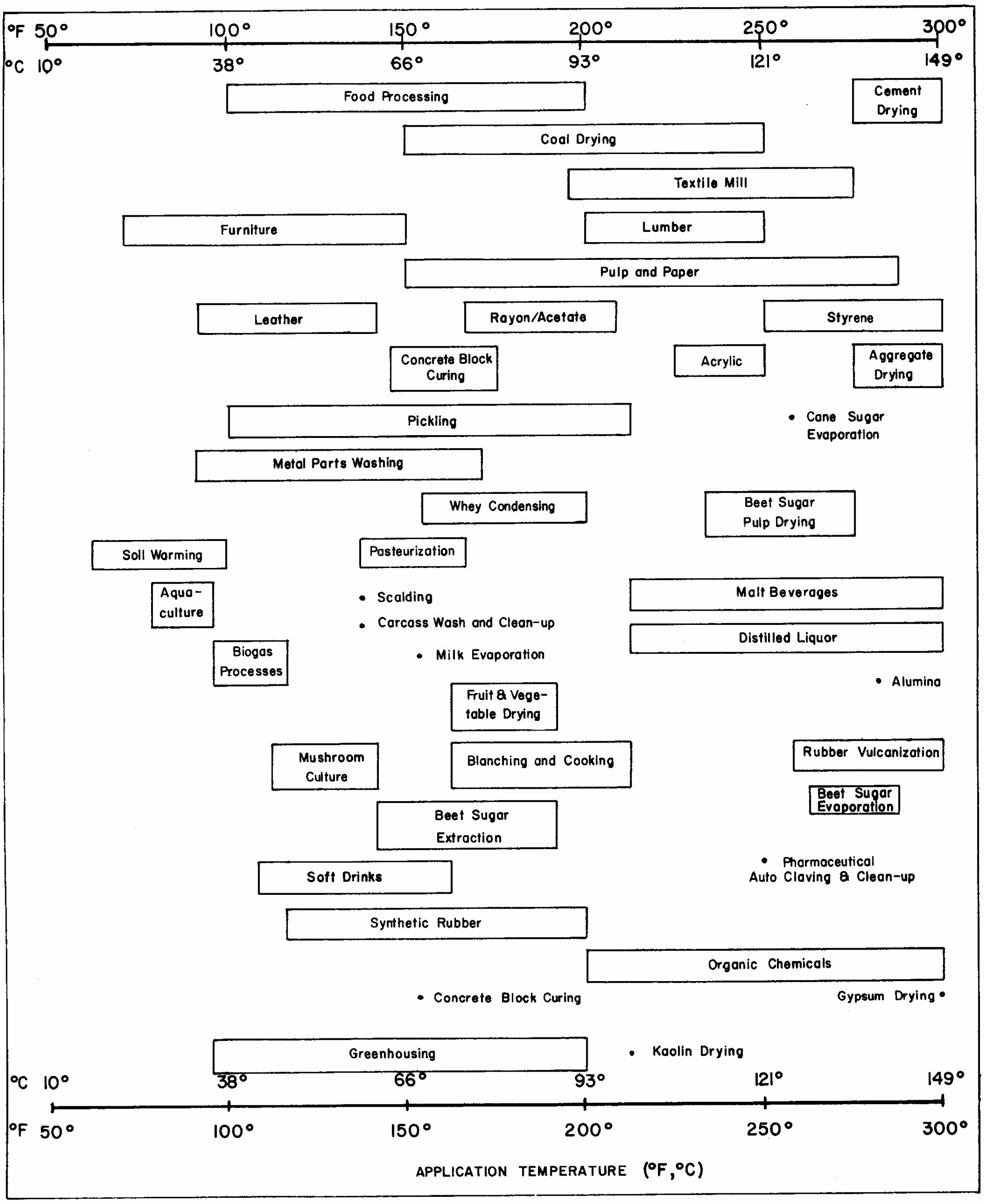

FIGURE 2: Application temperature range for some industrial processes and agricultural operations (Lund, J. et al 1998)

Why is there not more use of geothermal heat in agriculture and industry?
In spite of proven long term success stories when it comes to agricultural or industrial uses of geothermal energy, new projects have been few and older ones have been shut down. To explain this one needs to look at some of the present constraints.

Lack of availability of steam:

- Steam sources are only found in volcanic regions.
- Steam can only be transported over relatively short distances (~2-20 km).
- Geothermal steam is not yet a “commodity” - it can not be purchased from a pipeline or at an industrial park.
- Most installations to-date are dedicated to a single user.
- There are few geothermal developers.
- The development of geothermal fields takes a long time (5-8) years.
- Temperature and pressure limitation of geothermal steam:
  Delivery pressure is usually limited to the range 5-10 bar-g. This pressure is common in fuel fired industrial boilers. The corresponding steam temperature is 159-184°C but it means that the reservoir temperature has to be at least 200°C or 250°C.

Financial:

- The initial investment cost is high for geothermal field development, drilling and distribution. Equivalent to buying all the "fuel" up front for decades of operation.
- The transport distance from the geothermal field is limited to few km for steam and several tens of km for water due to cost and loss of pressure.
- High-temperature areas are mostly in remote volcanic regions away from population centres. “Green field” development.
- The cost of steam and water, although important, rarely exceeds 5% of the production cost of the given product.
- Investors are frequently skeptical and unfamiliar with this energy source.

Institutional:

- Lack of suppliers. There are very few companies selling geothermal steam and geothermal water to designated industrial parks. The present day operators are utilities or companies that have their primary interests in power generation but have as yet shown limited interest in small-scale industrial uses.
- Limited private development. Geothermal has not graduated from government enterprises or from geological- and volcanological institutes.
- The geothermal law and leasing of geothermal rights is new or non-existent. Obtaining environmental permits and resource concessions take time.

Environmental:

- Geothermal areas are usually found in rugged and beautiful natural settings. Many are within national parks or protected areas. Permission to exploit the resource can be difficult to obtain.

So what are the opportunities for Africa? The use of geothermal heat to dry agricultural products or natural materials is a possibility. One must then look for two things, the location of the resource and what can be grown or is available in the not too distant area. High value crops such as coffee, spices and fruits come to mind and a company that would specialize in the drying of a variety of crops could have work for a good part of the year. Such a custom dryer might also have facilities to steam sterilize the spices and other products for added value.

Candy production by melting sugar into bon-bon´s and adding flavors and color and also a variety of food products could be prepared in steam heated kettles. Processing of natural fibers is a possibility and a variety of dying cloths and washing of laundry.

There is also the possibility to dry fish or meat and this requires slow drying at not very high temperatures. If the temperature is too high it cooks the fish and also results in too high a drying rate that leaves the outside hard, thus hindering the drying process. Pre-cooking of food and food preparation on a large scale can also make use of geothermal heat. Industrial laundries can serve hospitals and the local community. Much of this does not require sophisticated equipment or large users. Thus granting access to steam or hot water close to the geothermal field can be of considerable economic benefit. This means that land will have to be developed for industries close to the geothermal fields as transportation of steam for more than say 2 km becomes uneconomic.

Industries that make use of steam for curing the rubber on retread tires, steam forming of wood for furniture, steam washing to degrease motor parts for rebuilding etc., are all examples of small industries that might benefit. In the rural setting of the geothermal areas, just having access to electricity steam and running water should be enough to spur good ideas. The main thing though is that ANY steam consuming industry can use geothermal steam in much the same way as it would use steam from a conventional boiler.

7. GEOTHERMAL EQUIPMENT FOR INDUSTRY

Geothermal steam can be used directly in practically any process equipment, in some cases requiring minor modifications (Figure 3). The main modification has to do with the release of the non-condensible gases which are a part of the steam. The gases must be bled off continually together with the condensate. If this is not done the equipment becomes full of gas and new steam can not enter. When 1 kg of steam condensate is formed about 1-2 litres (at standard temperature and pressure, STP) of non-condensible gases will remain and have to be released from the heat exchange equipment. Conventional steam traps are not designed to handle such large gas quantities and thus a by-pass valve or a properly sized fixed orifice is installed in parallel with the steam trap. It is very important to avoid the accumulation of gas in the heat exchanger, because it will lower the temperature of the steam, in spite of the equipment being under full pressure. The lowering of the steam temperature is due to the increase in partial pressure of the gases, thus lowering the saturation pressure (temperature) of steam. By mounting pressure and temperature gauges on the condensate receiver one can determine whether the non-condensible gas bleed is adequate.

The danger of corrosion or scaling from geothermal steam is at times overstated. One must remember that the geothermal steam is almost as pure as distilled water. Its use is simple and reliable. No fuel fired boiler or water treatment system to take care of, nor fuel to buy. The steam is always available so the equipment can be kept hot when not in use, thus minimizing stand-by corrosion. The cited problems are mainly to do with the brine, but not the geothermal steam!

The steam piping material is always mild steel but the condensate pipes are usually stainless steel or fibreglass due to the corrosiveness of the CO_2 and low pH. Thin walled heat exchangers are frequently made from stainless steel, titanium or duplex steel. There are a few pitfalls to be avoided in design and material selection of geothermal steam installations. Having the appropriate design one can expect equipment life not to be very different from that using conventional steam.

To give a few examples of pitfalls:

- Do not use copper or silver alloys in contact with the steam as they are attacked by H_2S.
- Use stainless steel for condensate pipes or other corrosion resistant materials. Thin walled heat exchangers may also require special materials.
- Provide for release of non-condensable gases from heat exchange equipment, usually a by-pass at steam traps.
- Provide for good dispersion of the gases through tall chimneys and do not allow the gas to enter the buildings. Stop any steam leak occurring inside buildings as it will enter H_2S into the ambient atmosphere.
- Keep the piping and equipment hot or dry it out if it is taken out of service.
- Use H_2S filtered air for control rooms and for motor control rooms.
- Micro switches may have to be gold or platinum plated or hermetically sealed. Copper wire ends need to be tinned (dipped in molten tin). Coating of copper with “Vaseline” has been shown to help. These are practical precautions against H_2S corrosion where the air is contaminated.
- Use ball valves for small valves but gate valves of the rising stem type with stainless steel trim and hard-faced seats (master-valves for tight shut-off).
- Install fine mesh strainers to trap mill scale and corrosion products that become dislodged in new piping installations.

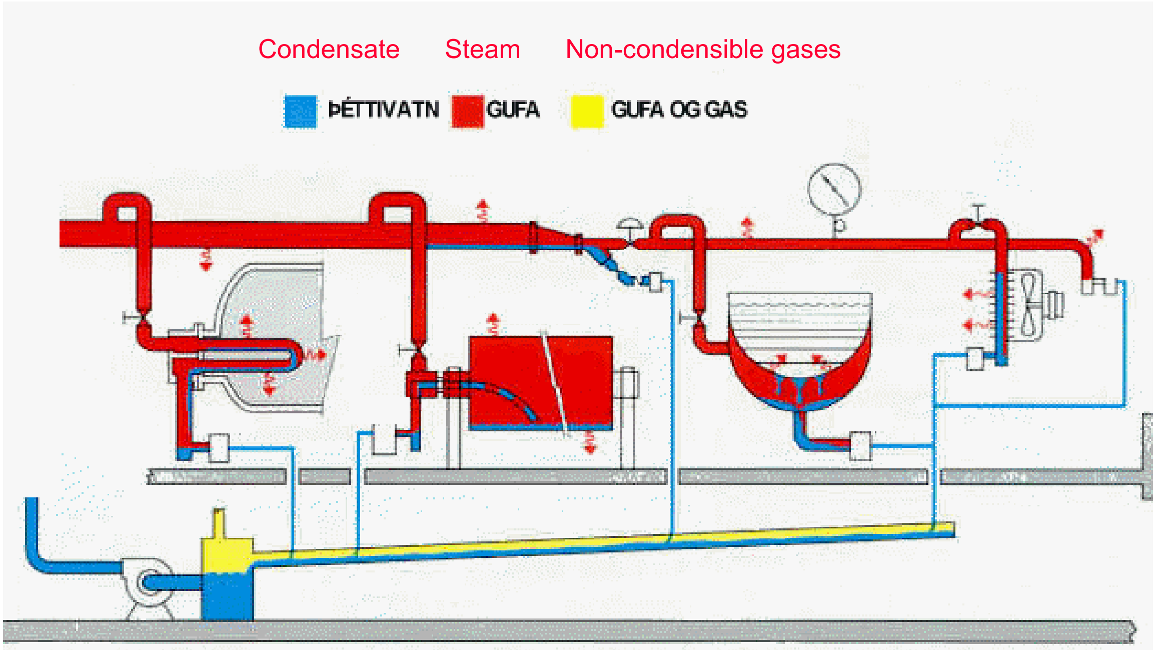

FIGURE 3: The most common types of steam heated industrial process equipment (Armstrong Co. modified)

8. AGRICULTURE

The main direct use in agriculture is for greenhouse heating that is at present reported in 30 countries, for heating the equivalent of 1000 hectares (Lund et al, 2005). There is also the use of geothermal heat for crop drying reported in 15 countries. Low temperature water is moreover used for aquaculture in China, USA, Iceland, New Zealand, and Italy.

There is an interesting use of the geothermal carbon dioxide gas for the enrichment of the atmosphere inside greenhouses to enhance the growth. For this to be possible the hydrogen sulphide gas has to be cleaned from the gas. In Iceland soft drink grade CO_2 is used with less than 0.1 mg/kg of H_2S.

Many farms in Iceland have been connected to a geothermal district heating system even if it means running a 1 km long branch to a single farm. This has in part been made possible by the introduction of plastic (PP and PB) pipelines. Most of the water is used for heating of the home and farm buildings. There are cases where the water is used for incubation of eggs, watering the animals and grain drying (Figure 4). Some years ago hot air drying of the hay in barns was used because of the wet climate. This has, however, been made obsolete due to the introduction of plastic wrapping of rolled hay bales.

9. CONCLUSIONS

The generation of electricity from geothermal sources will likely continue to be the most popular use. Direct use for space heating is likely to grow where the climate calls for it and also the use in agriculture. Interesting possibilities are found in spa and balneological use, for tourists and local people to enjoy. The industrial use will continue to play a minor role for a variety of reasons. All these uses are possible and have been successfully applied. Newcomers to the field should therefore include them in their plans, as may be appropriate.

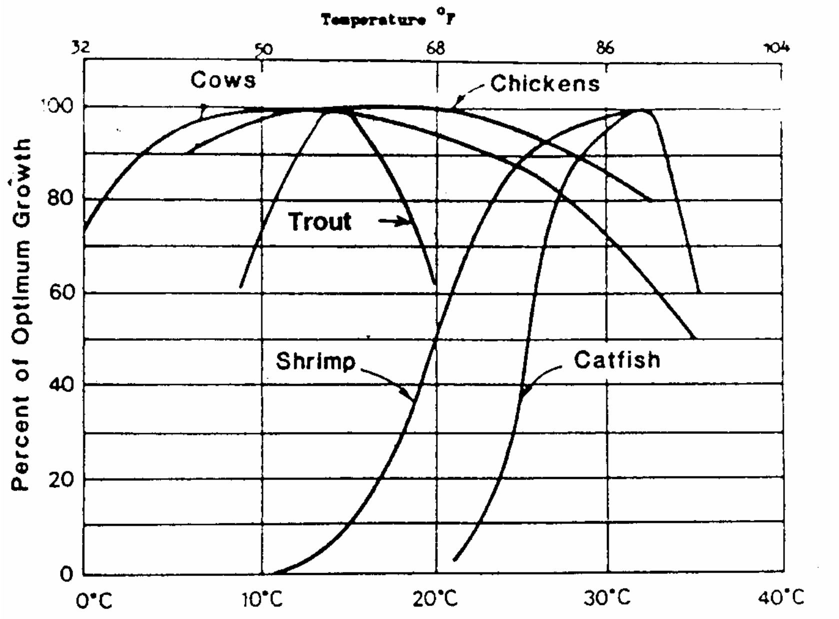

FIGURE 4: Optimum growing temperatures for selected animal and aquatic species (Lund J. 1996)

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