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SELECTIONS FROM EUROPEAN GEOTHERMAL CONFERENCES

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GEO-HEAT CENTER QUARTERLY BULLETIN

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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

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GEOTHERMAL CONFERENCES IN EUROPE EGC2003 AND IGC2003

Two important geothermal conferences were recently held in Europe: the European Geothermal Conference (EGC2003) in Szeged, Hungary (25-30 May) and the International Geothermal Conference (IGC2003) in Reykjavik, Iceland (14-17 September). This issue of the Quarterly Bulletin will feature several papers from these two meetings. The choice of papers was difficult, thus, those selected represent some unusual topics that are normally not discussed elsewhere in the geothermal literature.

EGC2003 was a geothermal conference that is held every four years in Europe; this one being hosted by the Hungarian Geothermal Association. This conference was attended by 161 people from 28 countries, mostly European, but also had attendees from Indonesia, Israel, Kenya, Mexico, New Zealand and the United States. Over 100 papers were presented, including approximately 30 poster presentations. A number of country update papers were presented as well as an overview paper on "Status of Geothermal Energy Amongst the World's Energy Sources" by I. B. Fridleifsson. Many papers covered two topics of particular current interest, on the environmental aspects and sustainability of geothermal energy. Other topics of major interest included the utilization and reinjection of cold fluids and thermal storage, geothermal heat pumps, proposed and existing power plants in Europe, and direct utilization of geothermal energy, especially for space and greenhouse heating. A majority of these papers were recently published in Vol. 32, No. 4/6 (August/December 2003) of *Geothermics*. A CD-ROM with all the papers is available from Dr. Franciska H. Kármán at: fanni@chemres.hu. Two papers from this conference are presented in this issue of the Quarterly Bulletin:

> "EIMY (Energy in My Yard) - a concept for practical usage of renewable energy from local sources" by H. Niitsuma and T. Nakata.
>
> "Titanium in the Geothermal Industry" by R. Thomas.

IGC2003 was a geothermal conference held to celebrate the 25th anniversary of the United Nation University's Geothermal Training Programme (UNU-GTP) in Iceland and hosted by the Geothermal Association of Iceland. The conference theme was "Multiple Integrated Uses of Geothermal Resources." Approximately 50 former graduates of the UNU-GTP attended the conference, representing 18 countries. The technical part of the conference stretched over three days with approximately 74 papers being presented by authors from 19 countries. Most notable was a report for the first time from Ireland, on their extensive geothermal heat pump installations, and reports from other non-traditional geothermal countries such as Uganda, Iran, Tunisia and Mongolia. A wide variety of papers were presented covering all aspects of geothermal utilization, from using low-temperature resources for geothermal (ground-source) heat pumps, to high-temperature for power generation and industrial uses. Over 90 papers are available in the 655-page *Proceedings*, edited by Dr. Einar Tjörvi Eliasson and Páll Ingólfsson from the organizing committee, at: ete@jardhitafelag.is. A future issue of *Geothermics* will include many of the papers from this conference. Four papers from the conference are presented in this issue of the Quarterly Bulletin:

> "Recent Large Scale Ground-Source Heat Pump Installations in Ireland" by S. O'Connell and S. F. Cassidy.
>
> "District Heating for Holiday Homes" by J. S. Fridriksson
>
> "The Drying of Fish and Utilization of Geothermal Energy: the Icelandic Experience" by S. Arason.
>
> "Meeting the Annual Heat Demand" by T. Jóhannesson and T. Ólafsson.

I would like to thank Dr. Franciska H. Kármán, chairperson of EGC2003, and Dr. Einar Tjörvi Eliasson, chairperson of IGC2003, for allowing the Geo-Heat Center to publish selected papers from their conference in this issue of the Geo-Heat Center Quarterly Bulletin. The author attended both conference and was impressed with the organization and hospitality shown by the organizers. A number of field trips to various geothermal projects in the area were also part of the conferences, illustrating the many diverse uses of geothermal energy. The conferences were a tremendous success, bringing together many geothermal experts from all over the world - ideas were exchanged, problems discussed and contacts made for future work. This will hopefully keep geothermal in the "spotlight" and promote future geothermal development throughout the world.

John W. Lund
Editor

EIMY (ENERGY IN MY YARD) A CONCEPT FOR PRACTICAL USAGE OF RENEWABLE ENERGY FROM LOCAL SOURCES

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INTRODUCTION

To maintain a sustainable civilization throughout the 21st century, it appears necessary that humankind utilize renewable energy sources to the maximum degree. Although various efforts are underway in various countries to develop renewable energy, they are still far from sufficient. Geothermal energy is a reliable and environmentally benign source and is one of the most competitive of the renewable resources. However, this view is not universally shared by the general public. Moreover, the current low price of fossil fuels, combined with deregulation of the electric power industry since 1990, has made it very difficult for new geothermal power plants to compete (Murphy and Niitsuma, 1999).

Given this situation, a workgroup was assembled recently in Japan to investigate strategies of geothermal development that are consistent with the expected earth environment of the 21st century. The recommendations of the group were presented as a report in May 2002. Central to their proposals was the concept of EIMY - Energy In My Yard which advocates the development of integrated renewable energy systems that are customized to the needs and resources of local communities. Such systems not only increase net renewable energy utilization, but also benefit the local economy and energy security in the area (Murai, 2002 and Niitsuma, et al., 2002).

In this paper, we describe the concept of EIMY and the role of geothermal energy within it. An analysis of cost and environmental benefit of an integrated renewable energy system is presented. We also discuss problems to realize the EIMY in a local area.

STUDY ON A STRATEGY OF GEOTHERMAL DEVELOPMENT IN JAPAN

The study was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). Group members are listed in Table 1. To date, geothermal energy in Japan has been developed as a substitute for oil energy since the oil crisis. No adequate study has been done to evaluate the potential of geothermal energy as a renewable energy consistent with the earth environment. Internationally, geothermal energy is recognized and categorized as a new and/or renewable energy together with solar, wind, hydro and biomass energy. However, in Japan, only solar and wind are classified as “new energies” that enjoy protection under the law concerning Promotion of the Use of New Energy enacted in 1997. Geothermal is not included. Moreover, in 2001, biomass was added to the list of renewable energies to be promoted by the New and Renewable Energy Subcommittee of the Advisory Committee for Natural Resources and Energy, but not geothermal. According to the Energy Supply and Demand Outlook presented by the Japanese government, future growth in geothermal energy is assumed to be zero. Consistent with this perspective, in 2001, the Ministry of Economy, Trade and Industry (METI) decided to cut the entire budget for research and development on geothermal energy. This decision was merely political.

Table 1. Members of the Study

H. Niitsuma (Tohoku Univ.) , representative
Y. Niibori (Tohoku Univ.)
N. Tsuchiya (Tohoku Univ.)
T. Nakata (Tohoku Univ.)
H. Asanuma (Tohoku Univ.)
S. Ehara (Kyushu Univ.)
R. Itoi (Kyushu Univ.)
T. Shoji (Univ. of Tokyo)
I. Takashima (Akita Univ.)
S. Kimura (Kanazawa Univ.)
I. Hashimoto (NEDO)
T. Tosha (NEDO)
I. Matsunaga (AIST)
M. Sasada (AIST)
H. Kaieda (CRIEPI)
K. Tezuka (JAPEX)
Y. Iikura (Japan Economic.Res. Inst.)
M. Yasuda (Development Bank of Japan)

Given the radical changes in the Japanese government policy on geothermal energy development, and the crisis it prompted, the group of geothermal experts set about conducting a systematic and scientific analysis of the role geothermal might play in meeting societal energy needs in the medium- and long-term.

The following items were the subject of discussion.

1. Geothermal energy as an environmentally benign energy source
   (a) Environmental benefit and impact
   (b) Reserves, quality, distribution and characteristics
   (c) Current development problems and their solutions
2. Geothermal energy in the Japanese society
   (a) Market and profitability

(b) Contribution to the local economy and its role as a diversified energy

(c) Current system of geothermal energy development, problems and solutions.

3. Key concepts in utilizing "geothermal energy consistent with the earth environment."
4. Strategy for a geothermal energy development in the 21st century.
5. Foreign strategy.

The group compiled a report of 220 pages, which was distributed to government officials, politicians, local government, local authorities, industries, universities, etc.

The report identified the following problems for geothermal development in Japan: (1) Geothermal projects have been strongly biased towards the development of 50 MWe-class power plants that could be connected to the national grid. This bias has effectively suppressed diversity in the methodology of optimally utilizing the resource: for example, the use of cascade or binary systems, and heat pump; (2) The market mechanism has not worked well, largely because the customer for geothermal developers has been limited to the electric power companies; (3) Lack of consideration of environmental aspects and objectives in geothermal projects; and (4) Geothermal power plants were not always seen by local inhabitants as a community resource but rather as being just as great a nuisance as the other type of power plants. Indeed, developments occasionally met with hostility from "onsen" (hot spring) communities, a reaction that erodes the incentive of people in surrounding area to introduce further geothermal facilities.

Based on the above considerations, the report advanced the concept of EIMY: Energy In My Yard as a rational usage of renewable energy resource for 21st century.

CONCEPT OF EIMY

EIMY is a local energy/economic system in which combinations of local renewable energy resources are utilized to the maximum degree that technical and economic considerations permit. Shortfalls and surpluses in local energy production are accommodated through an interface with the national grid (Figure 1). It should be emphasized that EIMY is a system for local people and is conceived to engender the converse reaction to that of NIMBY (Not In My Back Yard).

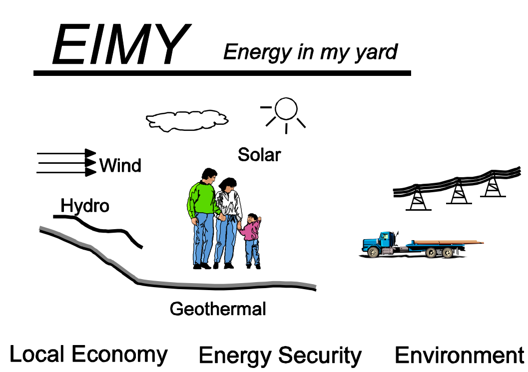

Figure 1. Concept of EIMY.

Figure 2 is a schematic diagram of business models for conventional energy/resources development in both growth and saturated periods. In the growth period, high density and/or high quality energy/resources are explored, developed and brought to market in pursuit of substantial profit. However, in the saturated period, the cost tends to climb because of progressive exhaustion of the resources and the attendant increase in difficulty of exploration and exploitation. Eventually, the resource loses its competitiveness in the energy/resource market. In contrast, natural, renewable energy resources are generally low density, but widely distributed and sustainable. It is, therefore, basically improbable that substantial profit can be derived in the short term from the development of renewable energy resources, except for limited locations that are blessed with high density/quality resources. In some countries including Japan, such favorable geothermal spots have already been fully developed. The same pattern may be followed for the development of wind power in the future.

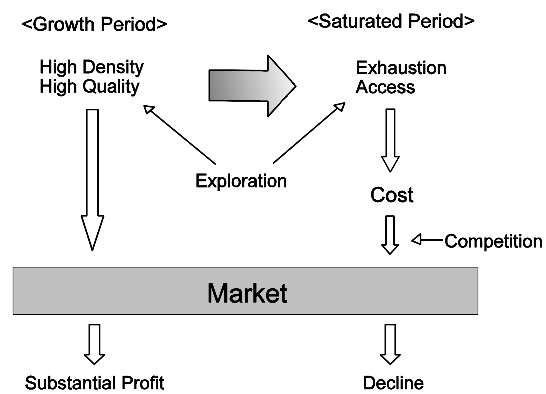

Figure 2. Business model for energy and resources development.

The conventional business model works well for developing favorable resources. However, the vast renewable resource that falls outside this limited category can only rationally be developed within the framework of a different business model that considers additional factors besides short-term profit. EIMY is one such model that also includes consideration of environmental benefit, contribution to the local economy through job creation, and local energy security. Such a revision of the business model would not only greatly extend the exploitable renewable resources, but would also lead to an increase in economic productivity of the host area. This in turn would provide an incentive for local people to utilize local renewable energy, and hence, contribute to the usage of green energy in the country as a whole.

The function of EIMY within the national energy supply system can be figuratively understood through analogy with the circulation system of the human body. EIMY represents the pumping function of the peripheral muscles for the peripheral arteries; while, the power supply to the national grid represents the pumping function of the heart for the main artery. Both functions are required.

INTEGRATED RENEWABLE ENERGY SYSTEM

The EIMY system seeks to utilize the optimum combination of every green energy resource that is locally available to the maximum extent that practical and economic conditions permit. Recognized resources include wind, solar, geothermal, hydro and biomass. We have applied a simulator, which can be used to identify the optimum combination, to the case of the hour-by-hour energy needs and source availability for a local village with a population of 9,000 in Iwate Prefecture in northern part of Honshu Island, Japan (Nakata, et al., 2002). There is no conventional geothermal activity in this area. The yearly average temperature is 8.3°C, with minimum and maximum values of -18.0 and 31.0°C, respectively. The simulated energy system consists of wind, photovoltaic (PV), biomass co-generation and conventional grid power for electricity supply, and of biomass-cogeneration, geothermal heat pump (GHP), petroleum and gas for heating. Shortfalls and surpluses of electricity from the renewable energy sources are accommodated with an interface to the grid.

The analysis uses a nonlinear energy modeling system to find the optimal configuration and operation of the energy system. Using this approach, the system is modeled as a market, with nodes passing information about energy demands and prices until equilibrium is reached. This equilibrium corresponds to a cost minimization. By this means, the most economical energy system will be configured and optimized (Lamont, 1994).

Figure 3 shows changes in the quantity of electricity supply during a windy period. The demand is shown by the central, relatively-regular periodic curve, and the optimized contributions from the various sources that combine to meet this demand are shown by the superposed colored areas below this curve. The area above the curve represents surplus electricity sold to the grid. The wind generator performs well and its electricity accounts for the major part of the total electricity generated. However, its production becomes insufficient during windless period at which time grid electricity is used. PV and biomass constitutes only a small portion of the electricity generated because of their costs.

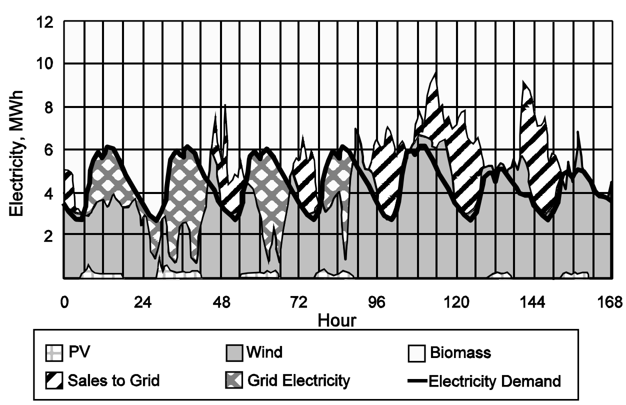

Figure 3. Electricity supply during a windy period.

Figure 4 shows changes in sources of heat supply for the same windy period. The GHP and petroleum serve as the main sources of heat, with the GHP favored during very windy periods. This is because the GHP runs on electricity; hence, the price of its heat is influenced by the price of electricity.

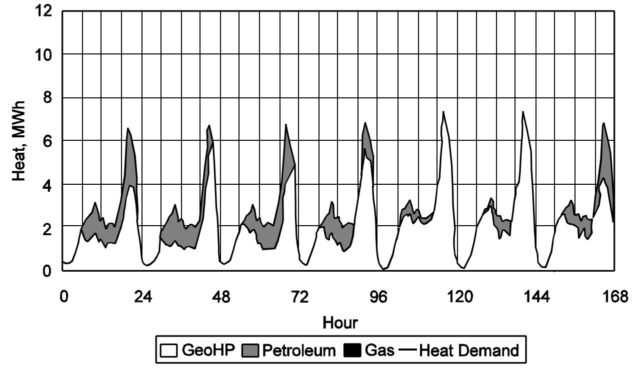

Figure 4. Heat supply during the same period.

The simulation-derived, optimum combination of installed capacity of the various renewable sources required to supply the village's energy needs throughout the year is shown in Figure 5. Evidently, this includes a large amount of wind and GHP, and a small amount of PV, biomass and petroleum.

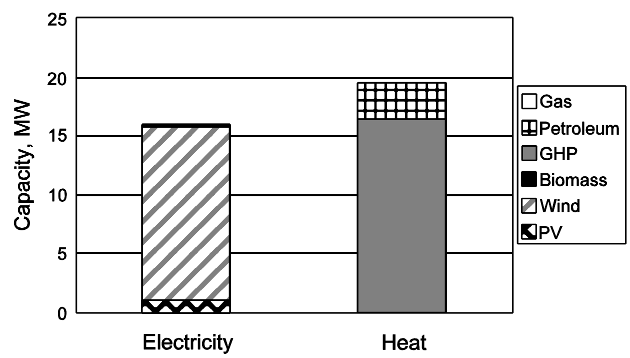

Figure 5. Optimized capacity of renewable energy sources.

CO_2 emission from the integrated renewable energy system in the village is compared to that from the conventional energy system in Figure 6. The optimized renewable energy system proposed here would reduce CO_2 emissions by 79% and hence, contribute significantly to the reduction of fossil fuel combustion.

Figure 7 shows the annual cost of meeting the village's energy needs with an integrated renewable energy system as compared with conventional sources. The costs include fuel, operating and capital investment expenses. The renewable energy system can reduce the annual cost by 15%. If sales of wind electricity to the grid during windy periods are included, the reduction increases to 23%. It should be emphasized that the calculations were performed using current market prices of commodities. The imposition of a carbon tax would improve the cost benefit even more.

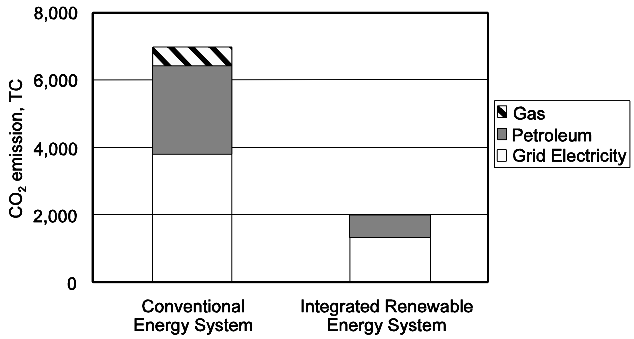

Figure 6. Suppression of CO_2 emission with the integrated renewable energy system.

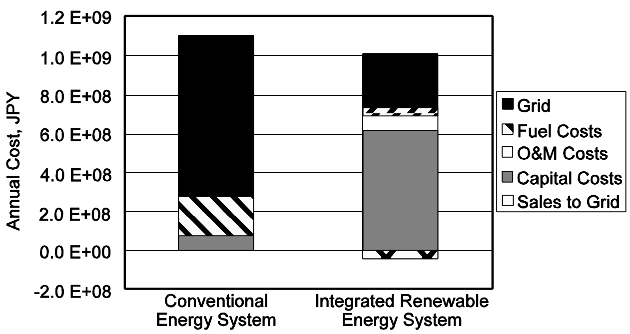

Figure 7. Comparison of annual cost between conventional and renewable system.

The analyses we have conducted make it abundantly clear that wind electricity and GHP are both necessary in order to optimize renewable energy systems economically in the rural areas. On the contrary, significant PV and biomass co-generation capacity are not installed in the proposed system. This is because the capital cost of wind electricity is lower than that of PV, and there is little difference between the ancillary operating costs of the two. The price of wind electricity is quite low, varying between 3 cents/kWh and 5 cents/kWh; whereas, the current price of grid electricity used in households is 23.3 cents/kWh in Japan. Thus, wind electricity can supply rural areas at one-fifth the price of current electricity sources. This allows GHP to supply heat at low prices, as the power source of GHP is electricity.

As shown in this example, the integrated renewable energy system has great advantage over the uncoordinated utilization of renewable resources. The optimum configuration of a renewable energy system for a given site will vary according to availability of energy sources, local climate conditions, demand patterns and costs of component.

GEOTHERMAL TECHNOLOGY WITHIN THE EIMY SYSTEM

Geothermal energy will play a key role in the EIMY system as was demonstrated by the example in the previous section. It is relevant to ask what are the essential features of geothermal that make it so suitable for the EIMY system? One feature is consistency with the environment and the other is ubiquity. Zero emission and sustainable production are essential features for the consistency. With regard to the latter, the technologies of reinjection (Cappetti, et al., 1995) and HDR/HWR (hot dry rock/hot water resources)are important. Technology to facilitate stepwise increases in production rate and monitoring are also important for sustainable production, because an optimum production rate in a geothermal system is usually difficult to estimate in advance, and it is reasonable to start with a lower rate. The technologies of HDR/HWR, binary system and heat pump taken collectively allow subsurface heat to be exploited from a diverse range of depths and conditions, and thereby greatly enhance the ubiquity of the geothermal resource. In this regard, it is necessary to compile a new database that shows the true picture of geothermal energy resources in a given area rather than just high density/quality resources. In the case of HDR/HWR, small systems of less than 1 MWe will be more useful for the EIMY system.

REALIZATION OF EIMY

For EIMY systems to be developed to the point of supplying a significant part of a nation's energy needs requires a considerable supportive infrastructure. Figure 8 shows a possible organizational chart of entities and links that might support a national EIMY system. As a first step, inhabitants must be informed about the benefits of introducing a renewable energy system, and be given financial incentives to install one. This financial and information support might be provided by local government and other advisory organizations. Because the contribution to the local economy is one of the major features of the EIMY, the renewable energy system should be constructed and maintained by local industries. However, it is unreasonable to expect that they will have enough knowledge to design and construct systems optimized to local conditions and resources themselves. It is, therefore, important that there exists a supporting organization such as consulting companies, national institutes, universities, etc., which has expert staff and maintains a database. The machinery and materials needed in the construction of the system should, whenever possible, be provided by central industries at reasonable cost. An association, which includes local and central industries, a national institute and universities, should be established with government support in order to further develop the requisite technologies. An insurance system is desirable to protect the local industries against cost increases arising from unforeseen circumstances. It must be recognized that there is always risk in developing natural resources.

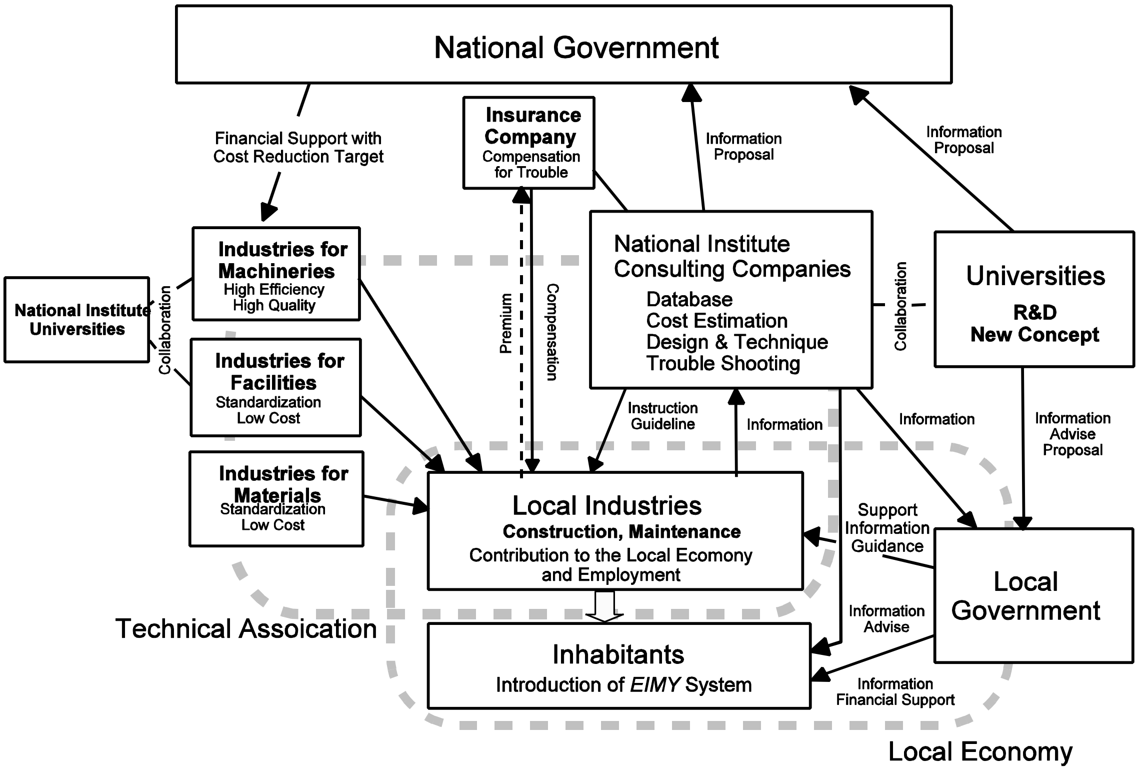

Figure 8. An example of economy system to realize EIMY.

Current regulations governing energy distribution in Japan do not favor the development of an EIMY system. For example, the Electric Utilities Industry Law in Japan gives exclusive rights to the electric companies to supply electricity in an area. This means that privately generated electricity from say a community wind turbine cannot be directly distributed to the inhabitants but must be sent through the electric company's grid. Thus, changes to the law are needed to allow the full benefits of EIMY system to be practically realizable, at least in Japan.

CONCLUSION

In this paper, we describe the concept of EIMY and the role of geothermal energy within it. EIMY allows the utilization of renewable energy resources that current business models deem to be unfavorable for exploitation. It also contributes the local economy, and provides for local energy security.

The integrated renewable energy systems have considerable advantage over independent utilization of renewable resources. The computer simulation for a rural area in Japan shows that an integrated renewable energy system with an optimum combination of resources can decrease not only CO_2 emission but also the cost, even though the installation and operating costs were assigned at current market rates, without weighting for advantages such as low CO_2 emission in the simulation.

Geothermal energy will play a key role in the EIMY systems. Heat pumps are of primary importance together with the geothermal technologies of reinjection, HDR/HWR, binary system. It is also important to compile a database that describes the expanded geothermal resource opened up by these technologies.

For EIMY systems to be developed to the point of supplying a significant part of a nation's energy needs requires a considerable supportive infrastructure. In order to realize EIMY, not only the technologies to utilize resources but also the establishments of economy system and the social system are required.

Renewable energy can supply a considerable part of the total energy requirements of an industrialized country. However, even if the political tide turns in its favor, it will take much time and effort to establish an EIMY system at the national level. Nonetheless, in some mostly-rural areas, it is possible to supply more than 100% of total energy needs by integrated renewable energy systems. These are obvious places to nucleate the development of EIMY. Subsequent extension of such areas to form a national EIMY system is one of the steadiest ways to decrease CO_2 emission in the world.

ACKNOWLEDGMENT

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RECENT LARGE-SCALE GROUND-SOURCE HEAT PUMP INSTALLATIONS IN IRELAND

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INTRODUCTION

Thermal energy consumption in Ireland is 1.032 Mtoe (155.67 TWh) for domestic heating. For the tertiary sector it is 0.421 Mtoe (63.50 TWh) (Dubuisson, 2002). Less than 1% of Irish households are heated using a heat pump. This contrasts sharply with Switzerland, one of the world leaders in heat pump technology, in which 67% of homes are equipped with a heat pump (Rybach and Sanner, 2000). The reasons for such a low number of installations in Ireland is due to a) low public awareness of heat pump technology and its advantages over conventional heating systems, b) air conditioning, which drove the heat pump market, especially in the US, is not required in Ireland, c) a lack of hot springs, a feature which usually promotes the use of ground source heat pumps (GSHP) and d) few installers to promote and install heat pump systems.

There are approx. 1000 domestic ground source heat pump installations in Ireland, typically in the range between 10 and 14 kW. Presently, there are approximately 18 large-scale commercial systems installed (Sikora, 2002). The installed thermal capacity in Ireland is 12 MWt. This paper deals with these large-scale commercial installations that have an output larger than 12kW. This figure was chosen so direct comparisons with other countries could be made using the data compiled by Lund and Freeston (2000) in their assessment of global geothermal energy.

While the number of GSHP systems currently installed in Ireland is low, there appears to be a large potential for growth in the area due to the prevailing climatic and soil conditions. Ireland has a mild climate due to the proximity of Gulf Stream currents in the Atlantic Ocean. The average annual air temperature is 9°C. The lowest mean daily minimum temperature in winter is 25°C. The country has both a high rainfall rate, 800 to 2,800 mm per annum, and high relative humidity values are between 71% and 91% (Met Eireann, 2002). These factors combine to ensure a large moisture content in the soil thereby increasing its thermal conductivity. Saturated soil has a thermal conductivity value up to four times greater than dry soil. The overall geological composition in Ireland, 40% of parent soil composition at depths of 1m and greater consists of either Sandstone or Limestone (Gardiner and Radford 1980). Sandstone has a thermal conductivity of between 1.28 W/mK and 5.10 W/mK. Limestone has thermal conductivity between 1.96 W/mK and 3.93 W/mK. Average ground temperatures at depths of 1m and greater are between 9°C to 13°C (Connor 1998). Horizontal collector ground loops may thus be used in Ireland, as the collector will not encounter external frost since diurnal damping depths are 0.2m for sandstone, and 0.1m for damp soil consisting of organic matter. This, together with the easy availability of land and the cheaper installation cost over conventional vertical borehole collectors, means than horizontal collectors are the most common form of collector type used.

Installed ground-source heat pump capacity for Europe is shown in Figure 1. Total European installed capacity is 1,577 MWt of which the estimated installed capacity for Ireland is 12 MWt. The European annual growth rate is 15% (Rivoalen 2001). Geothermal heat pump installations in the U.S. have total capacity of 1,356 MWt,

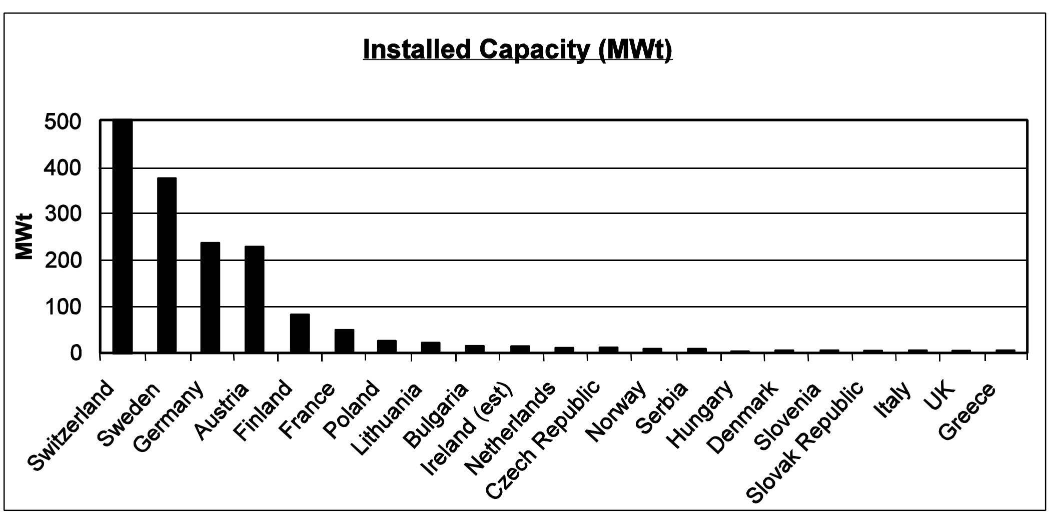

Figure 1. Installed ground-source heat pump capacity in Europe. (Lund and Freeston 2000).

comparable to the whole of Europe and are expected to increase at a rate of 10% annually (Lund and Freeston 2000). The estimated Irish annual growth rate is 44%. The high Irish growth rate is due to the lack of maturity in the heat pump market.

RECENT LARGE-SCALE GSHP INSTALLATIONS IN IRELAND

The following is an analysis of installations that have been recently installed in Ireland. Most have been extremely successful and indicate that ground-source heat pumps are

Table 1. Commercial GSHP Installations in Ireland

Building Location	Building Type	Installed	Collector Type	Collector Length (m)	Heat Pump (kW)	COP	Payback Period (years)	Estimated % CO_2 Emissions Reduction
Trinity College, Dublin (out of commission)	4 University buildings		Aquifer Boreholes (solar add-on)	4 x 12	6 Heat Pumps 450 kW	~ 4	1.5 - 4	60
Motor Tax Office, Tralee, Co. Kerry	Office	1999	Horizontal Closed Loop	5100	130 kW	3.7	4	52 (B. & E. M. 2001)
Share Hostel, Cork.	Residential	2002	Shallow Aquifer Borehole	20	100 kW	3.5		30
Mallow Swimming Pool, Co. Cork	Swimming Pool	1987	Geothermal Aquifer Borehole	75	100 kW	4	11.5	
Carbery GAA, Co. Kildare	Sports Hall	2003	Direct Expansion Horizontal	440	46 kW	6 (max)		
Dolmen Centre, Co. Donegal	Sports Complex	2000	Horizontal Closed Loop	1800	45 kW (Dohan, 2002)	~ 3		45
Marlton House, Wicklow Town	Residential with Swimming Pool		Horizontal Closed Loop	2800	40 kW	3.5	6 - 8	45
Sports Centre Churchfield, Cork	Sports Complex	1997	Horizontal & Vertical	600 Horiz 120 Vert	34 kW (Cork Corp., 2002)	2.37		
Camp Hill Community, Callan, Co. Kilkenny	Residential Care Facility	1996	Artesian Well & Tubing on Roof		30 kW	3.5	6 - 8	45
Spiddal, Co. Galway	Private dwelling &swimming pool	2001	Horizontal Closed Loop	1500	30 kW	3.5	6 - 8	45
An Seanscoill, Co. Galway	Old School House		Horizontal Closed Loop	1500	30 kW	3.5	6 - 8	45
Caheroye House, Athenry, Co. Galway	Country Hotel	2002	Horizontal Closed Loop	1500	30 kW	3.5	6 - 8	45
Navan, Co. Meath	Private dwelling & Offices	2000	Pipe in stream Closed Loop	1500	30 kW	3.5	6 - 8	45
Briar Hill	Large Private Dwelling			1500	30kW	3.5	6 - 8	
Landfill Site Office, Kinsale Road, Cork.	Office	2000	Horizontal Closed Loop	2400	28 kW	3.5	4.5 - 6	30
Pairc Gno an Daingan, Co.Kerry.	Technology Park Offices	2002	Horizontal Closed Loop	960	26 kW			
Green Building, Temple Bar, Dublin	Apartments / Office / Retail	1994	Vertical Borehole	150	23 kW	4.87	2.5	86 (Cooper 1995)
Heritage House Ballyhooley, Co.Cork	Residential Listed building	1995	Air & Horizontal in compost	1050	19 kW	3.3 – 3.6	6	45

well suited to the Irish climate. The majority of these large scale installations have been in showcase buildings which feature a range of renewable energy technologies such as solar panels for hot water heating, sustainable building design and layout and natural ventilation. Table 1 gives a summary of these installations.

Horizontal collectors are the preferred option as vertical boreholes are 4 – 5 times more expensive to install in Ireland than horizontal systems (O'Brien 2002). The horizontal collectors have all been installed at a depth of 1m with the exception of the Churchfield installation, which was installed at 0.5m depth. Ireland is not a densely populated country with only 52 persons per square kilometre thus accounting for the availability of land to install horizontal collectors. Typically ¾ inch diameter pipe is laid in parallel and manifolded together.

The borehole collector at Mallow Swimming pool uses the Mallow geothermal aquifer as its source. The water from this aquifer has an average recorded temperature of 19ºC. The borehole at Churchfield was installed to compare its performance with that of the horizontal collector. The horizontal loop proved to be more efficient (Collins, 1998). A vertical borehole was chosen for the Green Building in Temple Bar due to space restrictions. Some seepage from the bedrock also increases the heat pump COP. The decomposing waste at the Kinsale Road Landfill site is used as the heat source for the Administration building. The Share Hostel in Cork uses the Lee Valley aquifer, which, due to the heat island effect, has a water temperature of 12 –13ºC. The collector installed in Navan was placed on a stream bed and consists of stainless steel piping. Where possible, favorable geophysical features have been used for the collector, for example, the artesian well in Callan, Co. Kilkenny. In theory this should improve the system performance, however, the systems have not been monitored so the reduction in energy consumption has not been quantified.

The six heat pumps installed in Trinity College, Dublin range in size from 50 kW to 150 kW. The 30 kW systems in Galway and Mayo are a standard size and the associated horizontal collectors are 1500m in length. Tralee Motor Tax office is the largest installation serving a single building.

Mallow Swimming pool payback period is significantly higher because the project was the first of its kind in the country and encountered much higher exploration costs to determine the heating potential of the aquifer. For the Green Building in Temple Bar, the payback period for the entire building is estimated to be 18 years. As ground source heat pumps are a much more commercially attractive solution than other forms of renewable energy, they have a significantly shorter payback period than the building as a whole. For the Tralee Motor Tax office, the payback period was good due to its use for both heating and cooling. This can be accounted for by the very low running costs for the GSHP system. For example, in February 2001, heating costs amounted to approximately 15 euros per week.

For the Tralee Motor Tax office, CO_2 emissions were reduced by 52% as compared with a BRESCU type-3 office building. For the entire Green Building in Temple Bar, the reduction was 86%. This reduction was enhanced by the inclusion of foliant species as well as other renewable energies. The heat pumps in Trinity reduced CO_2 emissions by 920,000 kg CO_2/kWh annually. In Churchfield, a natural gas fired boiler is running continuously so there is a neglible reduction in emissions. CO_2 emissions for the other buildings have been estimated based on heat pump annual energy consumption and using BRECSU CO_2 emissions indicators (BRECSU, 2000). The 45% reduction is based on a comparison with an oil-fired boiler while the 30% reduction is based on comparison with Natural Gas where it is available.

Future projects include geothermal heating systems for Nursing home and health care projects with floor areas between 1200 – 1800m^2 in planning or progress. The Ballymun regeneration project in Dublin plans to install ground-source heat pumps in five houses to evaluate their practicality in high-density urban dwellings (Sikora 2002). Macroom Environmental Industrial Estate is a project initiated by Cork County Council. The pilot building will use an open loop water source heat pump to provide heating for the building. A 200kW system is under construction for University College Cork utilizing boreholes in a gravel aquifer. Inniscarra Environmental offices will have a buried horizontal loop installation with a proposed total heat output of 42kW, due to start on site in Sept 2003.

DISCUSSION

Running costs for GSHP systems in Ireland are significantly lower than other forms of heating. For example, a domestic oil boiler has running costs 66% greater than a ground-source heat pump. However, the high initial investment may be a deterrent to prospective users. Installation costs are 40% greater than oil or gas fired boilers, the most common forms of residential space heating, and 50% greater than electric storage heaters (O'Brien 2000). This is largely due to the lack of competition installing ground-source heat pump systems and the high cost of heat pump units. As the environmental and cost saving benefits of ground-source heat pumps becomes more widely known, this should encourage growth in the market and so reduce the initial installation costs. Organisations such as The Geothermal Association of Ireland, Sustainable Energy Ireland, and government funded Energy Offices at both national and local level are raising the profile of ground-source heat pumps in Ireland.

The increasing urbanization of Ireland will require GSHP installations to become more compact. An alternative to borehole heat exchangers is to install the collector under or in building foundations. This technology has never been applied in Ireland although it has been developed extensively in Austria mainly using foundation piles containing HDPE piping with brine as the heat transfer fluid. Collector piping has also been installed in raft foundations and diaphragm walls (Brandl, 1998). This technology has also been implemented in Canada for a 211 kW heat pump capacity system under an office building (Caneta, 1999) and in the US for a 6-ton (21kW) sub-slab heat pump installation (Drown et al., 1992). A project is currently underway at Cork Institute of Technology to install a collector under the footprint of a building (O'Connell in prep.). The aim of this project is to demonstrate the technical and economic feasibility of locating collectors in the foundations of buildings in Ireland. This, it is hoped, will make the use of GSHP in the urban environment more widespread in Ireland.

Ireland exceeded the maximum permissible greenhouse gas emission target set by the Kyoto protocol at 13% over 1990 levels in 1999. To limit energy related CO_2 gas emissions, renewable energy may be used to reduce emissions of CO_2 by over 4.25 million tonnes which is over 35% of Ireland's target (Kellett, 2002). Ground-source heat pumps may contribute greatly to this reduction as they reduce CO_2 emissions by between 30% and 100% as compared with conventional heating systems (Dubuisson, 2002).

CONCLUSIONS AND RECOMMENDATIONS

The majority of the projects detailed in this paper have received funding incentives from local, national or EU level. It is hoped that these buildings will demonstrate the commercial viability of ground source heat pumps to the wider public and so increase the take up of this technology. The potential for ground source heat pumps in Ireland is extensive. At present the percentage of heating requirements met by heat pumps is insignificant. The potential primary energy savings for residential and tertiary sectors is 2.426 TWh/year equivalent to 80,000 units as estimated by Sustainable Energy Ireland. These would reduce CO_2 emissions by 617,000 tonnes CO_2/year and the primary energy requirement for heating would be cut by 5%. The extra investment required would be 602.6 million euros (Dubuisson, 2002).

The barriers preventing this potential from being realized include: higher capital cost of GSHP systems; higher perceived risk; price distortions (external cost of fossil fuels, subsidies for infrastructures); unfavorable market characteristics; lack of installation experience; absence of quality standards and, finally, low level of awareness among the general public and decision makers in government and county councils.

To encourage greater use of GSHP systems, the following measures should be undertaken:

- Subsidies for installation of domestic heat pumps as well as the existing subsidies for developers.
- Certified installers.
- Standards for new building codes with regard to technical/economic considerations for heat-pump installation.
- Standards for use of heating and cooling systems in buildings with air conditioning.
- Restrictions on use of fossil fuel and direct electricity heating.
- Carbon fuel tax.
- Continual research and development of heat-pump systems specially designed for conditions in Ireland.

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MEETING THE ANNUAL HEAT DEMAND

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Introduction

This paper describes a study of the optimum utilzation of a low-temperature geothermal field in one of the larger cities in China. The task of how to utilize a low-temperature geothermal field is a practical one. In its most general form, the goal is to find a solution where as few wells as possible need to be used. The demand of power for space heating is unfortunately not uniform and there is a peak demand during the coldest days. To meet the demand, a trade-off has to be considered to combine geothermal energy (low running costs) and conventional boilers (low investment cost) for the lowest overall energy cost. Not only must the project be evaluated on an economic basis, the environmental aspect also plays an important role and should be given due consideration.

LOAD CURVE

The district heating load depends strictly upon two factors: weather conditions and thermal insulation of the buildings in question. The weather conditions encountered are continental, i.e. cold winters and hot summers. The insulation (resistance to cold during cold days and vice versa) is estimated to be R = 0.93 (m^2K)/W (or k = 1.08 W/ m^2K). An average apartment is 65 m^2 inhabited by roughly three persons. The total load for an area of 400,000m^2 of housing, during an average year is 65 GWh. Of those, 46 GWh are used for space heating, while the remaining 19 GWh are used for heating of domestic hot water. Figure 1 depicts the average load duration curves for the appropriate buildings in the area. Curves are set forth assuming three different values of total floor space to be heated.

The geothermal field in question has been explored during recent years. Its production potential has been estimated from wells already drilled. Based on a pre-feasibility analysis of the wells, the estimated annual average flow from each well is 20 l/s of 70°C water and the maximum flow 35 l/s. All additional wells in the field are expected to posess the same capacity. In Johannesson and Olafsson (2203), the authors regard the different approaches of meeting the heat demand, for a short period, when these constraints are relaxed.

As can be seen in Figure 1, the utilization of the geothermal energy increases with the size of the total floor space. The smallest area considered consists of 400,000 m^2 of floor space, and at maximum demand times, the peak power demand is 11 MW. The utilization of geothermal water and the peak power demand increases, as the total floor space increases. In the case of a total floor space area of 1,000,000 m^2, the maximum demand for peak power is 44.2 MW.

Figure 1 also shows that when the peak geothermal utilization of the water is reached (around the 150th and 75th day on the chart for 800,000 m^2 and 400,000 m^2 of floor space respectively), the lines representing geothermal utilization at higher loads are not fully parallel. This occurs since the return temperature from heating systems at different relative loads is not constant.

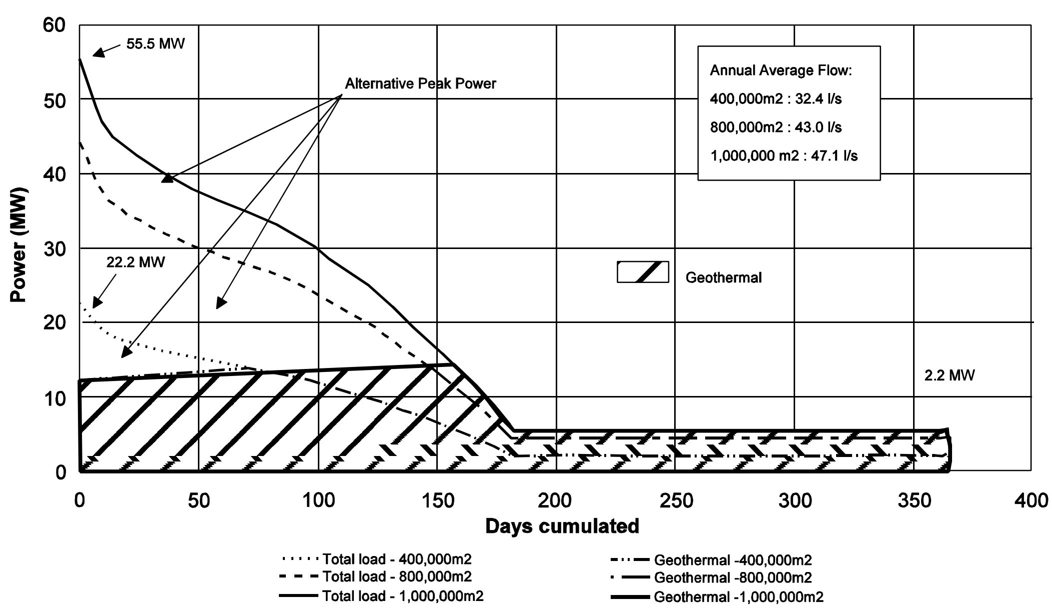

Figure 1. ***Indicates the geothermal usage of two 35 l/s production wells and one reinjection well for three given values of heated floor space.***

The annual flow of geothermal water exceeds the permissible limits for two production wells (2 x 20 l/s) for the larger areas (i.e., for 800,000 m^2 and beyond). Thus, when the total floor space is larger than 400,000 m^2, three or more production wells are needed to meet the demand, or the use of alternative peak power sources.

ALTERNATIVE PEAK POWER SOURCES

Alternative peak power sources evaluated are boilers and heat pumps. Boilers can be driven with various kinds of fossil fuels or natural gas while the heat pumps can be driven with electricity or heat (compressor or absorption heat pumps). For this study, the potential peak power sources considered are a natural gas boiler and an absorption type heat pump, driven by a natural gas boiler station.

THE PRICE OF ENERGY

The price of energy differs greatly between geothermal energy sources and their alternatives. The costs influencing the energy price are the initial investment costs of the district heating system and the system's operational costs. Investment cost consists of all equipment and its installation, and any related work (e.g., drilling of wells) but does not take into account costs related to exploitation rights. Operational cost consists of basic operational costs (such as maintenance) and fuel costs (fossil fuels or electricity). Table 1 shows a comparison of typical investment costs per produced MW, as well as operational costs per GWh. Investment costs and operating costs set forth in Table 1 do not include costs related to distribution systems nor house connections.

Table 1. Typical Basic Investment Cost and Operational Cost for Different Sources of Energy

	Initial cost / MW	Running cost / GWh
Geothermal	\$450,000	\$50
Boiler	\$40,000	\$30,000
Heat pump	\$240,000	\$18,000

Table 1 is only instructive for a geothermal system in this particular geothermal area.

With total floor space of housing amounting to 400,000 m^2, the district heating demand can be met by using various energy sources in combination. The following table summarizes the associated costs, investment and operational, now including costs associated with distribution systems and house connections for each of the options. It also shows an estimate of the emitted CO_2. All values are set forth for weather conditions encountered over an average year.

A general assumption would be to assume that the lifetime of the power plant is finite. When the power plant is shut down, the wells and boilers are assumed to be worthless, for the sake of simplicity. Under these conditions, a known formula can be used to calculate the accumulated present value of the project. This formula is as follows:

$$PV = I + A * \sum_{n=1}^{N} \frac{1}{(1+r)^n} = I + A * \left(\frac{1 - \left(\frac{1}{1+r} \right)^N}{r} \right) = I + A * PV_N$$

for finite N's (1)

where: PV: present value,
I: Total investment cost,
A: Total annual operational costs,
N: number of years,
r: interest rate.

Using formula (1) and the values provided in Table 2, the present value (cost) of the district heating system's life cycle cost can be calculated as a function of the system lifetime. Figure 2 shows the results, for a total floor space of heating of 400,000 m^2. In Figure 2, system 2-1 means 2 production wells and 1 reinjection well; system 3-1 means 3 production wells and 1 reinjection well, and so on. In Figure 3, the interest rate is assumed constant at 6% per annum.

As seen in Figure 2, the most economical way to heat the 400,000 m^2 of floor space is to use system 2-1 and an 11 MW boiler, unless the system is intended to operate for 3 years or less.

When the total floor space is 800,000 m^2, many other different combinations of heat sources can be put forth. These combinations are listed in Table 3.

Table 2. The Investment and Operating Costs in 1000 \$ for Various Ways of Meeting the Annual Heat Demand and Their Respective CO_2 Emissions in Tons. The Total Floor Space of Housing is 400,000 m^2.

Power Sources	Investment Costs	Annual Average Fuel Costs	Annual Operational Costs	Total Annual Operational Costs	Annual Average CO_2 Emissions
22.2 MW boiler only	3,610	1,980	91	2,071	14,022
System 2-1 + 11 MW boiler	10,530	181	263	444	1,368
System 2-1 + 10,5 MW heat pump	12,570	107	314	421	805
System 3-2 + 5 MW boiler	13,980	20	350	370	163
System 4-2	15,230	1	381	382	17

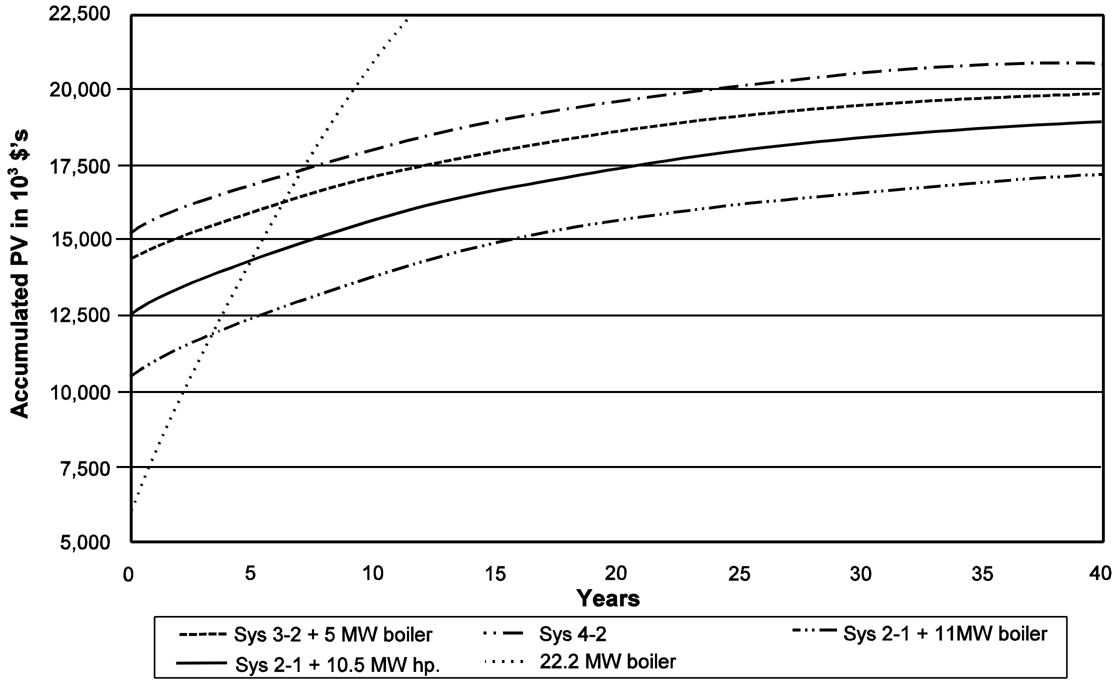

Figure 2. ***The present value (cost) of the district heating system's life-cycle cost as a function of system life. Total heated floor space is 400,000 m^2.***

Table 3. **The Investment and Operating Costs in Thous. $ for Different Ways of Meeting the Annual Heat Demand and Their Respective CO_2 Emissions in Tons. Total Floor Space is 800,000 m^2.**

Power Sources	Investment Costs	Annual Average Fuel Costs	Annual Operational Costs	Total Annual Operational Costs	Annual Average CO_2 Emissions
44.4 MW boiler only	4,590	3,960	115	4,075	28,044
System 2-1 + 32 MW boiler	12,660	1,487	317	1,804	11,224
System 3-2 + 26 MW boiler	16,010	929	400	1,329	7,501
System 4-2 + 20,5 MW boiler	17,610	469	440	909	3,569
System 4-2 + 10,5 MW heat pump + 10 MW	19,690	300	492	792	2,297
System 5-2 + 15 MW boiler	21,270	224	532	756	2,081
System 5-2 + 10,5 MW heat pump + 4,5 MW	19,210	159	480	639	1,596
System 6-3 + 9,3 MW boiler	22,530	597	563	1,161	233

As indicated in Table 3, the solutions for a total floor space of 800,000 m^2 are not mere duplications of the solutions for a total floor space of 400.000 m^2. For instance, the system 2-1 and a 11-MW boiler solution, for 400.000 m^2, are not duplicated but has changed to system 4-2 and a 20.5 MW boiler; since, the tap water load does not double as the area doubles.

The resulting present value of the district heating life cycle cost is considered for 800,000 m^2 in Figure 3. Figure 3 compares the different options over time, and by doing so, it gives an overview of the most economical combination of power sources.

The graph indicates that all attractive long-term solutions involve at least four production wells. One way to utilize the geothermal field would be to have a cautious preliminary drilling schedule, since the solutions differ very slightly. When four production wells and two reinjection wells have successfully been drilled, a decision could be made whether to add one more production well. This decision should above all be based on experience regarding the previous six wells (4-2). If, the total area of housing is expanded further than 800,000 m^2, towards a total floor space of 1,000,000 m^2 or even higher, additional wells seem to become more feasible than other alternative options, based on these two scenes. In such a case, a geothermal utilization time-schedule has to be laid out to simultaneously meet all needs of the area.

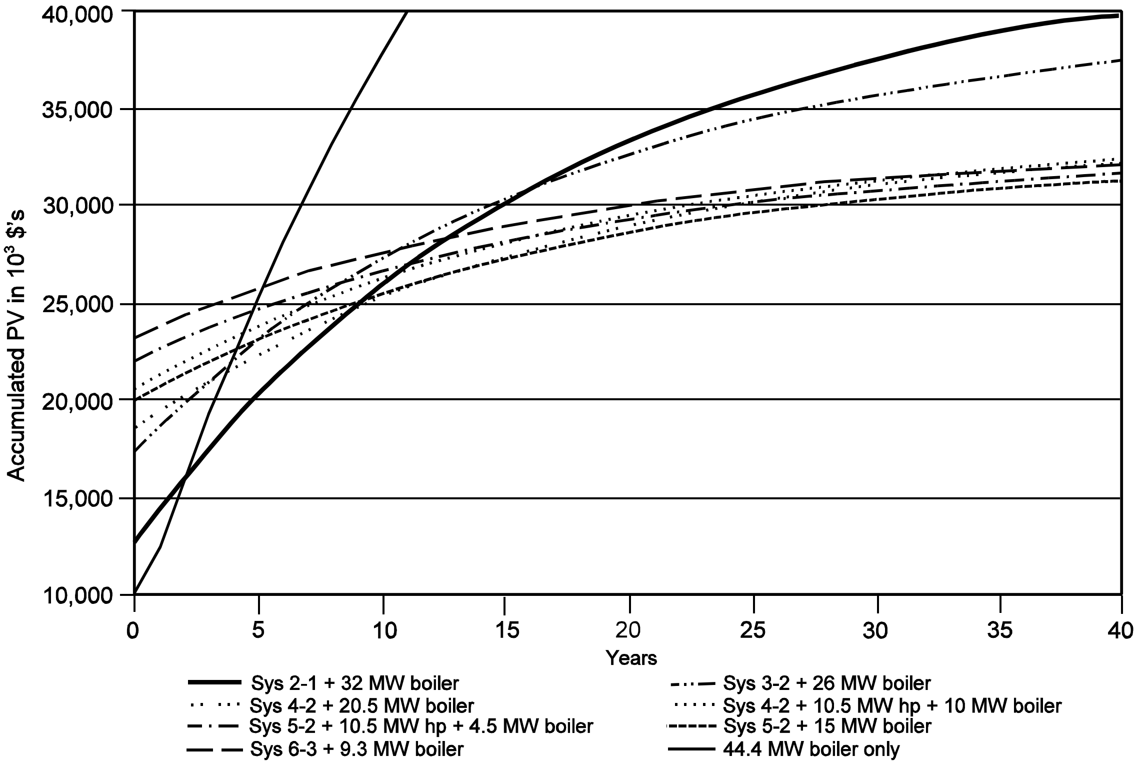

Figure 3. The present value of the district heating life cycle cost as a function of system life. Total heated floor space 800,000 m^2. The result for a 44.4-MW boiler is only shown partially.

ENVIRONMENTAL ASPECTS

The estimated annual emissions of CO_2 for all options have been set forth in Table 2 and Table 3. Air pollution is a serious problem in some areas of China, partially since large amounts of H_2S, SO_2, NO_x and CO_2 are emitted when the predominant energy source, coal, is burned in power plants. For this reason, it might be feasible to select the more expensive solutions since they reduce overall pollution to a larger degree.

The Global Environment Fund (GEF), and other global funds such as the Prototype Carbon Fund (PCF), have provided grants to various geothermal projects, similar to this one. The policy of these funds is to grant a specific amount for each ton of CO_2 not released to the environment, compared with traditional methods. Here, an initial grant of \$4/ton CO_2 over a period of 25 years (discounted at r=3.60%) will be considered for comparative purposes only. This amount has been granted from GEF, and similar institutions, in geothermal projects e.g. in East-Europe and is in line with environmental policies as of today. The expected amount of the grant for the various combinations of heat sources is shown in Table 4. If an environmental grant, as indicated in Table 4, is taken into account and added to the analysis of the district heating system, the order of feasibility does not change in the first phase of the project (400,000 m^2) and the changes for the second phase (800,000 m^2) are small (<5%).

PRICE TO THE CONSUMER

When the total cost of the energy has been evaluated (Figures 2 and 3), a price to the consumer can be calculated. The following table indicates the minimum price that each customer should be charged for the different combinations in order to break even. Table 5 assumes that all users pay for their energy usage, at the right time.

As indicated in Table 5, an environmental grant does not influence the price to consumer greatly. Values in Table 5 assume a zero residual value of all system components. In actuality this residual value is higher since the distribution system, boilers, heat pumps, etc., can be sold as second hand equipment when operations cease. The consumer price should thus be somewhat lower (3-10%), depending on the system's age upon closure. For some areas in China, a comparison with a pure boiler would be the most logical one, but in this case it is assumed that the use of pure boilers have already been permitted.

CONCLUSIONS

Different approaches of meeting the annual heat demand exist. The comparison between different selections discussed in this report can be of assistance in a final selection for housing areas of 400,000m^2 and 800,000m^2 in specific parts of China.

Table 4. Expected Environmental Grants in $ for the Various Combinations

Area (m^2)	Sys 2-1+boil.	Sys 2-1+hp.	Sys 3-2+boil.	Sys 4-2+boil.	Sys 4-2+hp.	Sys 5-2+boil.	Sys 5-2+hp.	Sys 6-3+boil.
400,000	825,000	862,000	904,000	913,000	-	-	-	-
800,000	1,097,000	-	1,369,000	1,596,000	1,679,000	1,693,000	1,725,000	1,814,000

Table 5. The Prices for the Project to Pay Off in 10 and 25 Years

		The Price to Pay Off in 10 Years				Price to Pay Off in 25 Years			
Power Source	**Area (m^2)**	**US$ kWh**	**US$ m^2**	**Yuan m^2**	**Yuan/m^2 w. grant**	**US$ kWh**	**US$ m^2**	**Yuan m^2**	**Yuan/m^2 w. grant**
22.2MW gas boiler	**400,000**	**0.044**	**6.71**	**55.0**	**55.0**	**0.040**	**6.19**	**50.8**	**50.8**
System 2-1 + 11 MW boiler	400,000	0.030	4.60	37.8	35.5	0.020	3.15	25.8	24.5
System 2-1 + 10,5 MW heat pump	400,000	0.034	5.24	43.0	40.6	0.023	3.49	28.6	27.2
System 3-2 + 5 MW boiler	400,000	0.037	5.73	47.0	44.5	0.024	3.71	30.5	29.0
System 4-2	400,000	0.039	6.06	49.7	47.1	0.025	3.92	32.1	30.6
44.4 MW boiler	**800,000**	**0.040**	**6.18**	**50.7**	**50.7**	**0.038**	**5.85**	**48.0**	**48.0**
System 2-1 + 32 MW boiler	800,000	0.028	4.23	34.7	33.2	0.022	3.45	28.3	27.4
System 3-2 + 26 MW boiler	800,000	0.029	4.48	36.7	34.8	0.022	3.33	27.3	26.2
System 4-2 + 2.5 MW boiler	800,000	0.027	4.20	34.4	33.7	0.019	2.93	24.0	23.1
System 4-2 + 10.5 MW heat pump + 10.5 MW boiler	800,000	0.029	4.39	36.0	33.7	0.019	2.98	24.4	23.1
System 5-2 + 15 MW boiler	800,000	0.028	4.26	35.0	32.6	0.019	2.88	23.6	22.3
System 5-2 + 10.5 MW heat pump + 4 MW boiler	800,000	0.029	4.47	36.6	34.2	0.019	2.93	24.0	22.7
System 6-3 + 9.3 MW boiler	800,000	0.029	4.53	37.2	34.6	0.019	2.95	24.2	22.7

Estimated geothermal flows used in this analysis are based on a pre-feasibility analysis and the accuracy of the posted results depends on the exactness of results from that analysis. If the results from the pre-feasibility analysis turn out to be typical for geothermal wells in the area, this analysis may turn out to be useful in meeting the annual heat demand in the area.

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DISTRICT HEATING FOR HOLIDAY HOMES

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NEW MARKETS FOR DISTRICT HEATING

In Iceland most of the traditional market for district heating services has been covered. Most of the cities, towns and villages that are close to geothermal energy utilise it for space heating. Reykjavík Energy however has taken the initiative and began looking at different market areas for district heating, namely holiday homes, normally located in the countryside. The demand for district heating in holiday home areas has caught us at Reykjavik Energy by a surprise. District heating is a commodity celebrated by many holiday homeowners.

Figure 1. Group of holiday homes.

The purpose of this paper is to describe projects in this market area hoping it may challenge others to start looking for new ways to utilize geothermal energy and work towards increasing the utilization of geothermal energy in the energy markets.

THE CONCEPT OF HOLIDAY HOMES

It is becoming more and more popular in Iceland to have access to holiday homes, either by owning or renting short term. There is a strong desire for many urban residents to escape from the rat race into the tranquillity of the countryside to relax and find comfort at a unique location chosen or developed by the escapee. Those who can, spend a lot of their time and effort in their holiday homes, building, maintaining, gardening and/or relaxing.

Holiday home areas are usually built on small section of 5 to 10 thousand square meters, which are normally built in clusters where services such as roads, waterworks and electricity are accessible.

The holiday home gives shelter from the harsh and rather unpredictable Icelandic climate. Typically the main occupancy is during the summer time. But summer time in Iceland is quite different from the typical European summer climate, as all sorts of weather can be expected.

Figure 2. Holiday home at an unique location

As can be seen from the weather data shown in Figure 3, the heating season lasts the whole year for holiday homes, or at least during its occupancy.

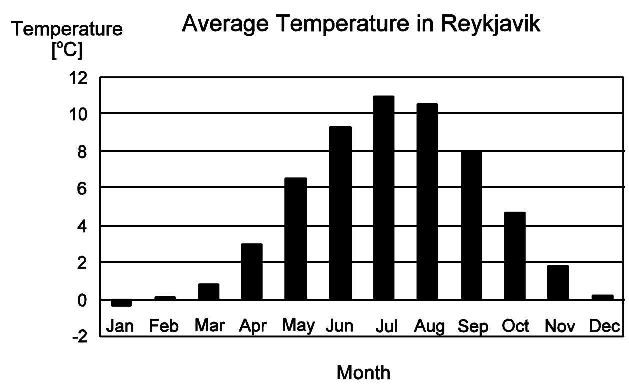

Figure 3. Average monthly temperatures in Reykjavik, Iceland.

Holiday Homes

Holiday homes can be categorized into two basis categories, privately owned and public usage (in some cases limited e.g. to union members).

Public Holiday Homes

The demand for public holiday homes is normally huge during the summer season. Every week is booked months in advance. For several reasons this time of peak demand is getting shorter, e.g. shorter school holidays and more concentrated vacation periods. Outside the peak periods most of the houses are vacant. This has put some strain on the owners; thus, increased utilization of the homes is essential for their financial well being.

Private Holiday Homes

The owners and the closest family and friends generally use private holiday house. The occupancy is normally more distributed and less frequent than for public holiday homes. Still, the demand for comfort is increasing; as attraction is needed for the children and grandchildren to come for a visit.

Increased Utilization

Holiday houses are normally far from being some kind of bungalows, as the investment is considerable and normally the holiday homes are quality houses. And the comfort shouldn't be less than at home e.g. demand for similar appliances as at home. Most holiday homes have some space heating appliances, electricity, gas or district heating which is becoming more and more common.

Considering the investment people and organizations have made in their holiday homes it does not come as a surprise that the majority of the owners wants to increase the utilization period of the houses. The houses must be inhabitable despite the climate and fully equipped with all modern appliances to provide the comfort and leisure. The best way to increase the utilization is to plug the holiday homes into a district heating system. Heat the houses all year round and the possibility to install a spa-pool (Icelandic: "heitur pottur"), which has a huge attraction for all generations.

Figure 4. "Heitur pottur" Spa-pool.

Holiday homes with access to district heating service and equipped with a spa-pools have higher utilisation than those without. Owners of public holiday homes are experiencing a boycott of those homes without spa- pools. Similar applies to new holiday home areas, those with access to district heating service are much more popular.

FEASIBILITY

The market for district heating in holiday home areas is definitely there. But there are of course few conditions that have to be met before the district heating service can be built. Necessary prerequisites are:

- Geothermal energy
- Market
- Feasibility

Geothermal Energy

Geothermal resources can be found in quite a few places in Iceland. Most of the geothermal energy located close to traditional market (e.g., towns and villages) have already been harnessed for district heating. Many holiday home areas are located in the vicinity of geothermal resources that can easily be harnessed. Other energy sources for the district heating such as electricity and oil are too expensive.

Market

Holiday home areas that are potential for district heating project have to be densely populated. The number of holiday homes must also be considerable. Those parameters are, however, case sensitive, based on the investment in each project.

Feasibility

Project must be planned ahead and its profitability must be determined. Availability of the geothermal energy, development costs, transportation and distribution must be planned and estimated. The income will then determine the feasibility with acceptable rate of return for the investment. Reykjavík Energy uses methods of cash flow analysis to determine whether projects are feasible or not.

GRIMSNES DISTRICT HEATING SERVICE

The first project on district heating for holiday homes, Reykjavík Energy initiated was in Grímsnes. Grímsnes is located 60 km east of Reykjavík and is located between the rivers Sogið and Hvítá.

Grímsnes Holiday Home Area

Over 1500 holiday homes have been built in Grímsnes. It was estimated that it is feasible to build a district heating in a part of the area, which covers approximately 750 holiday homes. This area is the most populated and concentrated making it the most feasible. It is not fully built yet; the estimated number of tracts is well over 1000. Our expectations are that most of the un-built sections will be occupied within 10 years.

The number of holiday homes in the neighbourhood is constantly growing. The demand for tracts is huge in this area. This gives us good hope for the future, extending the district heating in Grímsnes even further now that we have the basic structure ready.

The District Heating Service

The district heating service in Grimsnes was commissioned in December 2002, after approximately one year of construction and additional year for planning and design.

The Geothermal Resource

The geothermal field is located very close to the market. Three production boreholes have been drilled and the capacity of the most successful bore is 60-70 litres per second of 84ºC water. The chemistry of the water allows it to be distributed directly to our consumers and it can be used for washing and bathing.

Figure 5. Dilling rig "Saga" at location in Grímsnes.

The full capacity of the field is unknown but the above-mentioned boreholes can supply a total of 1200 holiday homes with sufficient hot water.

The Distribution System

The main supply pipe running through the area is of pre-insulated (Poly-Urethane) steel, dimensions DN 200, 150 and 100. For all dimension below DN 100 and throughout distribution network, we used pre-insulated PEX (cross-linked polyethylen).

The distribution network is of course a one-pipe system as no return pipes are necessary. The return water is discharged into the lava. The flexibility of the PEX pipes has an advantage over the rigid steel pipes. This has been especially helpful when following paths, bypassing trees or other structures inside the tracts.

The supply temperature measured at the holiday homes ranges from 55 to 80°C, depending on the distrance from the geothermal field and the number of connected holiday homes in the vicinity. The supply pressure varies from 2 to 6 bar.

Figure 6. Inside the main pumping station.

The Delivery and Sales

Reykjavík Energy connects the supply pipe to each customer in a cabinet normally located on the exterior of the holiday home. The customer connects his heating systems into the cabinet as well. By using the cabinet as a connection point Reykjavík Energy can have access to the connection at all times; thus, it doesn't matter whether the holiday home is occupied or not. Reykjavík Energy supplies bypass valve, filter and flow restriction into each of the cabinets. The customer supplies all other equipment necessary.

Minimum subscribed flow is 3 litres per minute, which is in most cases sufficient for heating a normally sized holiday home. The customers can add to the minimum flow according to their needs. Many customers with spa-pools have subscribed to additional one or two litres per minute.

Table 1. District heating tariffs in Grímsnes

Item	Cost [kr]	Cost [US$]	Cost [Euro]
Annual fee: -Min. flow 3 litres per minute	50,110	652	567
-Additional 1 litres per minute	10,420	135	118
Connection fees	110,471	1,438	1,250

Selling energy by restricting the flow does seem awkward at first, especially when energy savings are considered. The sale does not encourage the customer to save energy, but it encourages the utilisation of the peak flow to its fullest. Critics have claimed it would have been better to install meters at each holiday home and sell the energy by cubic meters.

The tariff structure was determined bearing two things in mind:

- The structure may not encourage customers to turn down the heating of the holiday homes during periods of non-occupancy, which normally are during winter periods. This would affect the neighbouring customers, decreasing the flow in the distribution system and increase the risk of frost damages in the system.

- With flow restriction at each holiday home it is easier to determine the simultaneous flow and therewith dimensions of the distribution network. In fact this means smaller diameters and less investment in the system as a whole.

Marketing

The most challenging task in this project is marketing part. It was impossible to predict the participation of holiday homeowners and their rate of connection to the district heating. In towns were district heating had been built, most of the potential customers hooked up within a year from its commissioning. It was, in most cases, far cheaper to use geothermal district heating service than electricity or oil. The encouragement to connect holiday homes to district heating is not only about money; it is about increasing the comfort levels and it enables extended utilisation of the holiday homes all year round.

Figure 7. Geothermal connections in a country home cabinet.

The risks of the projects in regards to the marketing were identified and investigated by a team at Reykjavík Energy. Most of the foreseeable problems were solved before the construction began:

- Press releases, direct mail and meeting with the association of holiday homeowner in the areas were used to inform people about the plan to build a district heating service, get responses and discussion on the project.
- Reykjavík Energy prepared guidelines on how to connect to the district heating system and recommendations on how holiday homeowners should plan their heating systems. Simple things such for instance having a closed circuit heating system through a heat exchanger with anti-frost fluid circuling in the house, minimizing the risk of leaks in case of frost damages.
- Rule number one during construction, never go into a tract without consulting the owner on where and how to lay the supply pipe. By doing it this way the damage was minimised to the vegetation and structures. By consulting the owner, he made him partly responsible. Before the project started we expected to get a lot of claims regarding this issue, but as of today there has been relatively few.
- Tariffs are kept at a minimum to get as much participation as possible. Tariffs are very low when compared to similar district heating services. This required a cost focused project, where each part was tendered out to contractors, to keep the cost at a minimum.
- Extended services were offered to those interested. Reykjavík Energy offered to design and build the heating system for the holiday home owners. The interest caught us by surprise, as almost 10% of applicants made use of this service.

Achievments

The participation in Grímsnes district heating has been very good, beyond our original estimates. Of 750 holiday homes, 500 have applied for connection to the district heating and 350 have already been connected to the district heating service. This achievement is considerable taking into account the fact the district heating was commissioned in December 2002.

The priority over the next two years will be to increase the number of participants, getting to those 250 holiday homes that have not participated and keeping a close eye on the neigbouring holiday home areas with possible extention of the district heating in mind.

OTHER PROJECTS BASED ON THE GRIMSNES MODEL

Munaðarnes

Next year, Reykjavík Energy will begin construction on a new DH service in a holiday home area approximately 100 km north of Reykjavík. 160 holiday homes are in the area, with about 90 of them are publicly owned by a union. The number of holiday homes is much smaller there than in Grímsnes; thus, the tarfiffs will be somewhat higher as the investment will be distributed over fewer customers.

Hlíðaveita

The district heating service Hlíðaveita, which has been in operation since 1980s, was recently aquired by Reykjavik Energy. Hlíðaveita was originally built to service approximately 15 farms located in the vicinity of the geothermal field that is utilised. With increased contruction of holiday homes in the area that have been hooked onto the DH system and the fact that the district heating service was primarily designed to service farms, it does not come as a surprise that the service is in need of restructuring. Reykjavík Energy sees the potential in this area as a holiday home area servicing more than 500 homes within few years. The DH service will be restructered and build according to the model used in Grímsnes.

SUMMARY

Based on the experience from Grímsnes, we are convinced there is a future for district heating services in holiday home areas and other sparsely populated areas. We have considerable knowledge about the market and learned much, which will come in handy in future projects of similar kind during the construction phase.

TITANIUM IN THE GEOTHERMAL INDUSTRY

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INTRODUCTION

The realization that titanium exhibited remarkable corrosion resistance (TIMET) in oxidizing chloride environments led to some of its first applications in the chemical process industry [CPI], such as wet chlorine gas coolers for chlor-alkali cells, chlorine and chlorine dioxide bleach equipment in pulp/paper mills, and reactor internals for pressure acid leaching of metal ores. Now many applications have greater than 25 years of service history, including heat exchangers, reactor vessels, and distillation columns in areas of chemical plants, refineries, chlorine and chlorine chemicals production, pulp and paper mills, and salt plants.

TITANIUM CHARACTERISTICS

Table 1 lists the titanium alloys well suited for use in the CPI (Grauman, 1998). The materials in this list exhibit a baseline corrosion resistance in chloride media that includes resistance to general corrosion, pitting, and stress corrosion cracking (except grade 5). While certainly not a complete list of titanium materials available, this list provides for all the basic requirements (physical, mechanical, & corrosion) needed for the majority of CPI applications. Each material can be listed by UNS or ASTM designation. Following the convention popular in the U.S., the titanium materials will hereafter be referred to by their ASTM grade designation.

Table 1. Titanium for the CPI

TIMET Designation	Nominal Composition	ASTM Grade	UNS Design	Alloy Type	Strength	Features
TIMETAL@ 35A	Unalloyed Titanium	1	R50250	Alpha	Low	Most formable grade-for cladding & PHE
TIMETAL@50A	Unalloyed Titanium	2	R50400	Alpha	Low	Most widely used titanium grade-best comb. of props.
TIMETAL@ 50A Pd TIMETAL@ 50A 05Pd TIMETAL@ 50A Ru	Ti-0.15Pd Ti-0.05Pd Ti-010Ru	7 16 26	R52400 R52402 R52404	Alpha	Low	Added corrosion resistance over grade 2
TIMETAL@ 65.A	Unalloyed Titanium	3	R50550	Lean Alpha/Beta	Medium	Added strength vs. grade 2
TIMETAL@ CODE 12	Ti-0.3Mo-0.8Ni	12	R53400	Lean Alpha/Beta	Medium	Added corrosion resistance & strength vs. grade 2
TIMETAL@ 3-2.5	Ti-3AI-2.5V	9	R56320	Lean Alpha/Beta	Medium	Cold formable, med. strength titanium alloy
TIMETAL@ 5111	Ti-5AI-1Sn-1Zr-1V-0.8Mo-0.1Si	32	R55111	Lean Alpha/Beta	High	High toughness/weldable alloy for plate/fasteners
TIMETAL@ 6-4	Ti-6AI-4V	5	R56400	Alpha/ Beta	High	Std. aero alloy-some SCC concerns in seawater
TIMETAL@ 6-4 ELI	Ti-6AI-4V-0.10	23	R56407	Alpha/ Beta	High	Low oxygen grade 5-no SCC but lower strength
TIMETAL@ 6-4 Ru	Ti-6AI-4V-0.10-0.1Ru	29	R56404	Alpha/ Beta	High	Added corrosion resistance over grade 23

A complete listing of chemical and mechanical properties for each popular mill product form (ie-strip, plate, bar, tubing, pipe, forgings, & castings) can be found in Volume 2.04 of the ASTM standard specifications. Generally the lower strength grades are the easiest to fabricate (TIMET), and are economically available as thin strip and tube, whereas the higher strength grades need to be hot formed into seamless pipe or forgings.

CORROSION RESISTANCE

The majority of titanium applications in the CPI have resulted from the excellent corrosion resistance it exhibits in common organic and inorganic media. In particular, the resistance to chloride containing media is first and foremost. Titanium resists general, crevice, and pitting corrosion and SCC in all near neutral chloride brine up to a minimum of 85-90°C. Grades with enhanced corrosion can extend this resistance to 300°C or more. Titanium's corrosion resistance relies upon the formation of a very thin oxide film, which occurs spontaneously in air or water. As long as this oxide film remains passive, corrosion rates for titanium will be insignificant. However, once destabilized, corrosion damage can occur very rapidly. Thus, it is important to understand the regions of stability for the oxide film. An important aspect of the passive nature of the oxide film is the necessity for oxygen either in the liquid or vapor phase of a process stream.

Titanium is immune to general corrosion attack in all natural, cooling tower, and high purity waters to temperatures in excess of 600°F. This includes seawater and brackish water, typically some of the most corrosive of environments for common engineering materials. Contaminants, such as metal ions, sulfides, sulfates, and carbonates do not affect the passivity of titanium in these environments. Utilities have installed nearly 400 million feet of welded titanium tubing in seawater cooled condensers without a single incidence of corrosion.

Reducing acids are most often the cause of general corrosion on titanium. These include the mineral acids hydrochloric, hydrofluoric, sulfuric, and phosphoric, and organic acids like oxalic and sulfamic. The resistance of titanium to these acids will vary according to alloy, acid type, concentration, and temperature. An example is shown for hydrochloric acid media in Figure 1. Titanium should never be used in the presence of hydrofluoric acid. Extremely high corrosion rates are observed even at ppm concentrations. Oxidizing acids, like nitric and chromic, pose little threat of corrosion to titanium due to the inherent stability of the oxide film under oxidizing conditions.

Besides precious metal alloying, another useful technique for extending the general corrosion resistance of titanium is with the presence of oxidizing ionic species in process media streams. Minute (ppm levels) quantities of certain multi-valent transition metal ions and other species, such as halogens, nitrates, oxychloro anions, and certain organic compounds can have dramatic effects on the corrosion rate of titanium. As an example, the corrosion rate for grade 2 titanium is reduced from about 800 mpy to 1 mpy in boiling 3% HCl with the addition of 100 ppm Fe^{3+}. Often, necessary inhibitor levels are present as contaminants in process streams, allowing use of titanium in environments that if pure, would rapidly attack the metal.

Crevice attack of titanium tends to be the limiting factor with regards to material selection for most CPI applications. Brine chemistry is a secondary issue, assuming chloride concentration is above the threshold level for

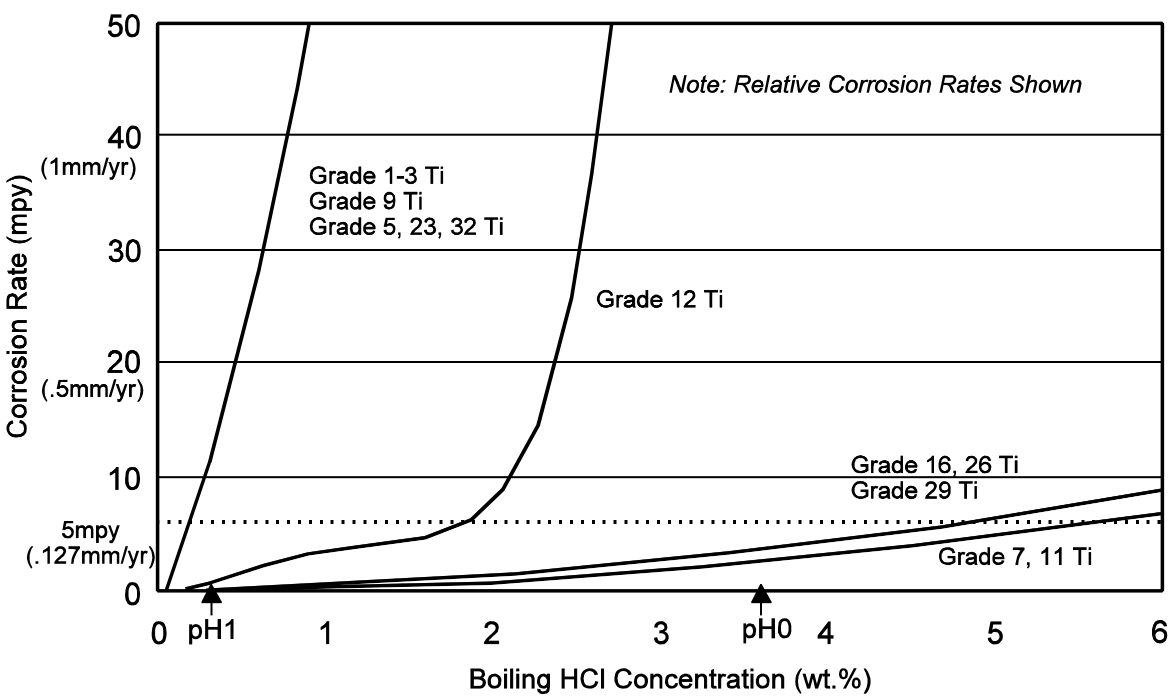

Figure 1. Relative general corrosion resistance of several titanium grades.

titanium, which is about 1000 ppm As shown in Figure 2 (a general guideline only), CP titanium can exhibit crevice attack at temperatures above about 80ºC, when the pH falls below about 9. Grade 12 reduces the threshold pH to about 3. Grades 7 and 11 (Ti-.15 Pd) exhibit remarkable crevice corrosion resistance, and are suited for even the most aggressive of environments where brine pH falls below 1. Lower cost options, such as grades 16 and 26 offer nearly identical crevice corrosion performance as grade 7. These grades allow the design engineer to select a more conservative (i.e., corrosion resistant) titanium grade if crevice corrosion is deemed a possibility, without incurring a substantial cost penalty. Grade 12 can be used to advantage in applications requiring moderately better corrosion resistance than commercially pure titanium and where the added strength can be utilized. Options other than alloy selection are also available to prevent crevice corrosion. These include grade mixing (i.e., use of more corrosion resistant and costly grades only in susceptible areas such as weld joints and flange faces), gasket selection and/or impregnation, and process modifications

Review of field and laboratory experience clearly indicates excellent corrosion resistance of titanium alloys to all geothermal brine environments (Schutz, 1984). Specifically, the titanium alloys evaluated proved to be, for all practical purposes, immune to general corrosion and stress corrosion cracking, regardless of fluid chloride level and /or temperature. In addition, their erosion-corrosion résistance was found to be unexcelled in high velocity geothermal brine/steam fluids.

Overall titanium alloys display good resistance to localized attack in geothermal environments. However, deposit crevice corrosion limitations of C.P. titanium and Ti-6A1-4V alloys are apparent in high temperature hypersaline brines. Crevice attack of C.P. titanium was observed with the hypersaline Salton Sea brine exposures only. This attack was not experienced in low to medium (< 15,000 ppm) chloride-containing KGRA fluids. In contrast, the Grade 12 titanium and Ti-Pd alloys resisted chloride crevice corrosion and pitting attack in all cases, including corrosion Salton Sea brine exposure.

ECONOMICS

Table 2 presents a relative cost comparison between the various grades of titanium. This can only serve as a cursory guide, as product form and fabrication cost differences could significantly impact these figures. Only titanium grades are shown in this table. However, as a general rule, grade 2 titanium costs are on a par (±10%) with the 6-Mo super austenitic stainless steels.

When examining overall costs (material, manufacture, and installation) for process equipment, often the higher material acquisition costs for titanium are diluted to a large extent by the other costs involved. The end result can often surprise design engineers that have a mindset to use titanium only as a last resort. Figure 3 presents data on vessel costs for the CPI, comparing titanium to stainless steel and other high performance metals.

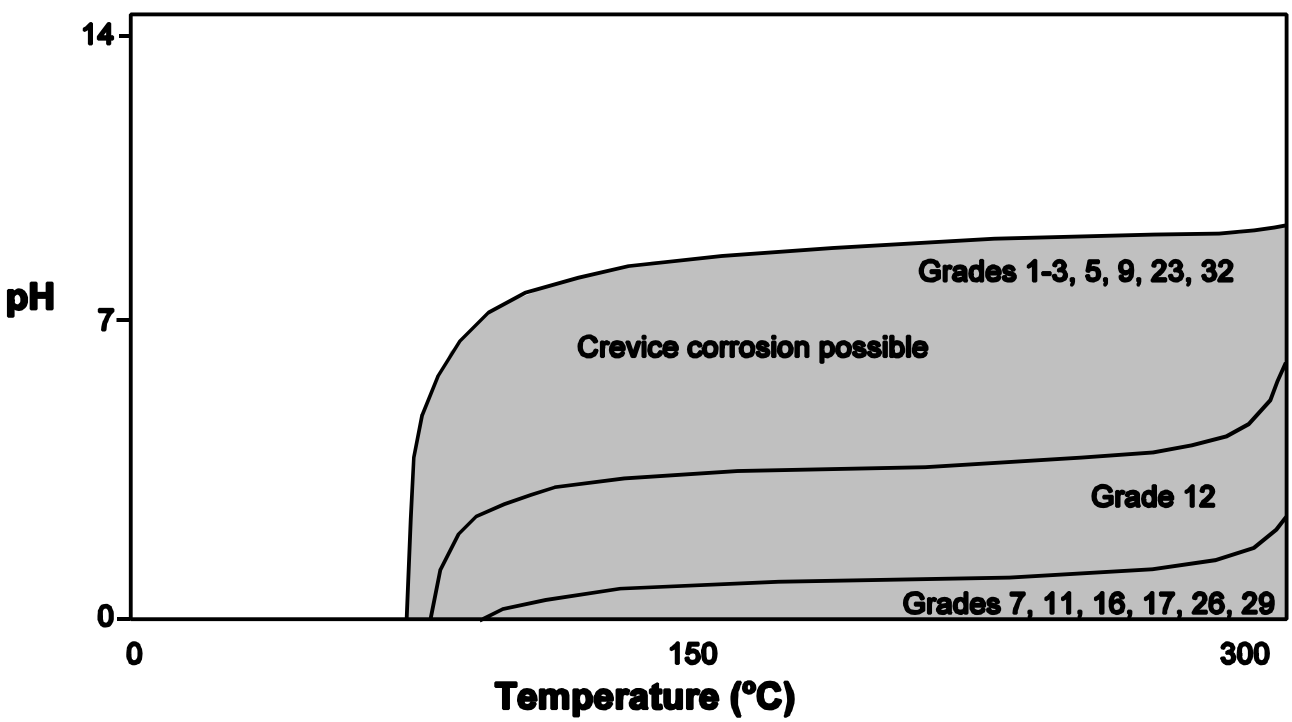

Figure 2. Crevice corrosion guidelines for titanium.

Table 2. Relative Cost of Various Titanium Grades

Titanium Grade	Approximate Relative Cost Ratios
1-3	1.0
12	1.25
16, 26	1.4
7, 11	2.25
9	1.3
5, 23, 32	1.5
29	1.8

Clearly, titanium can compete favorably with other metals used in the CPI. Titanium should always be viewed as one of several candidate materials for process equipment without any pre-existing notions of which material would be the most cost-competitive. This allows the engineer much more flexibility in the original design perhaps avoiding the pitfall of assuming a less corrosion resistant material will also be less costly.

APPLICATION CONSIDERATIONS FOR TITANIUM ALLOYS IN GEOTHERMAL SERVICE

Where to Use Titanium

Based on comparative cost and the performance reviewed above, titanium alloys are certainly viable candidates for geothermal system components when common stainless steels have previously failed or are anticipated to exhibit marginal performance. This would include equipment in which high reliability and near-zero corrosion allowances are required, from a performance, maintenance, cost and /or safety standpoint.

Consideration of titanium is promoted when chloride levels exceed 5000ppm and with temperatures greater than 100°C. When oxygen intrusion is possible, titanium alloys become preferred materials in geothermal systems because hot, oxidizing-chloride conditions are known to cause severe localized attack of stainless steel and nickel-base alloys. Oxygen entry into these systems can occur during brine well reinjection, brine processing, system leakage, equipment downtime, or brine residence in holding ponds.

Equipment surfaces exposed to direct hypersaline geothermal brines are obvious candidates for titanium. These include critical wellhead components, such as valves, gages, piping, and blowout preventers. For total flow geothermal systems, critical components exposed to two-phase brine additionally involve turbine components (blades, rotor, seals,

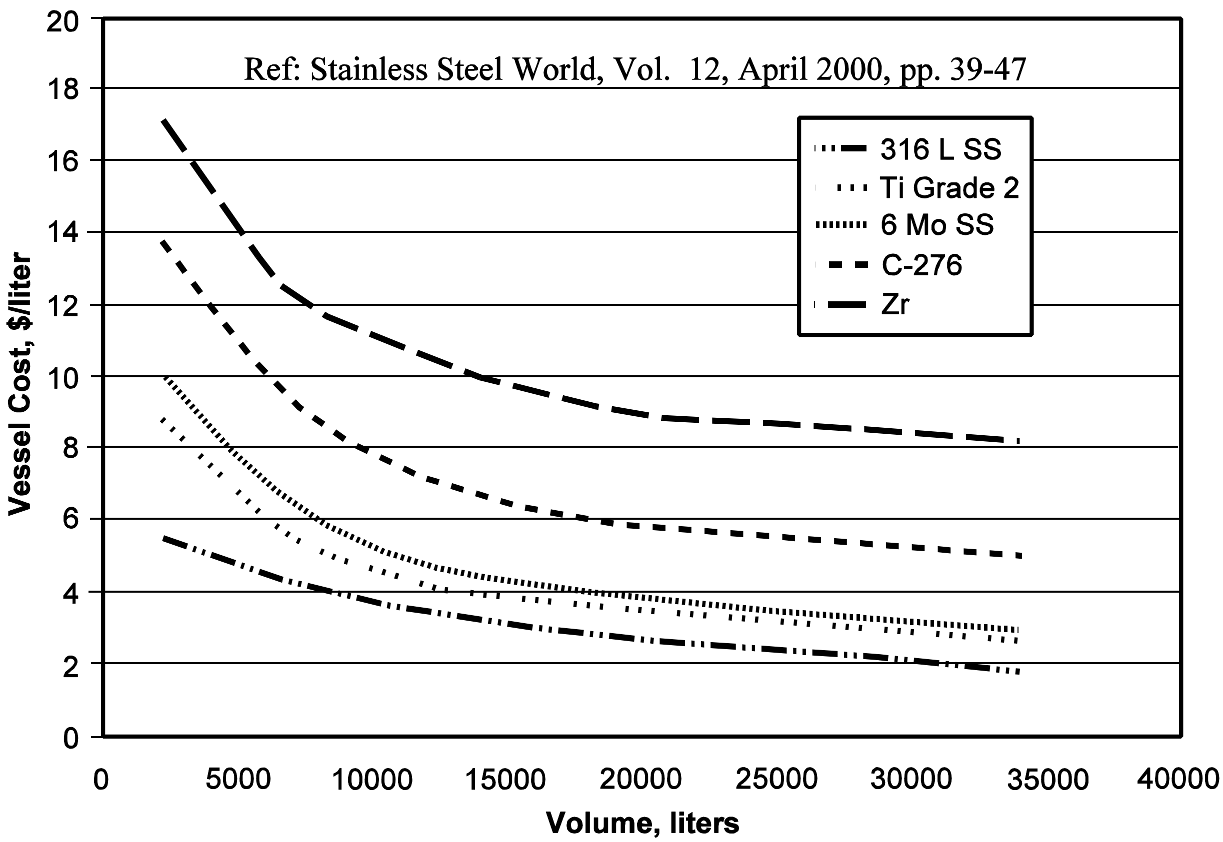

Figure 3. Cost comparison of high performance metals.

and shrouds), expansion nozzles, valves, venturis, steam separator components, and barometric condensers. Direct binary cycle geothermal systems require that binary heat exchanger tubes be immune to all forms of corrosion. These systems can also include brine reinjection pumps, which involve critical components such as impellers, shafts, and seals.

Flashed steam geothermal systems, which derive energy from medium to high salinity brines, are also good candidates for application of titanium alloys. These not only encompass equipment exposed to direct geothermal brine, including various stage separator (flash tank) components, but also equipment downstream of the separated steam. The need for titanium would depend on steam separation efficiencies, which determine chloride carry-over; and by system air leakage, which is more likely, to occur under that lower pressure conditions associated with separated fluid processing.

Multiple flash steam systems often include brine processing equipment, such as evaporator/crystallizers, to prevent scaling in downstream separators and associated piping. These represent potential problem areas, associated with brine concentration effects and possible entry of air, for which titanium should be considered.

Geothermal Brine Well Tubulars

The primary incentive for selecting Ti Grade 29 alloy tublar strings in geothermal brine well is hot chloride corrosion resistance (Schutz and Watkins, 1997). These alloys become especially attractive when total dissolved solids (TDS) in the brine exceed approximately 100,000 ppm, brine pH is less than or equal to 4, and/or downhole temperatures exceed ~230°C. Published corrosion data confirm that these Ru-enhanced alloys resist localized attack and stress corrosion in naturally-aerated or fully-deaerated sweet or sour NaCl-rich brines to temperatures as high as 330°C and pH's as low as 2.3, regardless of CO_2 and /or H_2S partial pressures.

Perhaps the most prominent example of the performance and economic merits of Ti-6-4-Ru alloy use in the energy industry today is in Salton Sea geothermal brine wells in Southern California. More than 1,000,000 lbs (450 tonnes) of Ti-Grade 29 hot rolled seamless tubulars have been produced for brine production and reinjection wells since the early 90's to handle these semi-sweet hypersaline (TDS ~ 260,000 ppm) NaCl-rich brines exhibiting reservoir temperatures as high as 315°C. These threaded and coupled 10.75 in (273 mm) and 13.375 in (340 mm) outer diameter tublar strings have been economic replacements for thicker steel and extruded Ti-38644/Pd tublars previously used for the following reasons:

- Grade 29 tublar strings offer a projected service life in excess of 15 years and can be permanently cemented-in.
- Elimination of the cost of steel string replacement, drill rig use, and associated well production downtime, which was incurred every 18 months or so. Additional cost associated with heavy metal and radioactive scale removal and disposal from corroded steel strings were also saved.
- Elimination of the risk of formation damage, total well loss, and/or string parting during steel string retrieval.
- Elimination of well bore plugging from iron-rich silicate scaling, particularly after steam flashing and during brine reinjection, which was aggrevated by steel corrosion products (i.e Ferrous ions). Reduced topside brine acidification (via HCl addition to ~pH4) now effectively inhibits silicate scaling during brine reinjection.

Grade 29 may be the only practical tubular material fully resistant enough to provide economic justification for development of high-temperature (<330°C), highly acidic (pH > 2.3) and sour geothermal brine fields for power generation in the Philippines.

It has also been suggested that Grade 29 well casing may enable a great expansion of geothermal energy generation by allowing sea water injection to depleted or inadequate aquifers, or to Hot Dry Rock geothermal energy facilities.

SUMMARY

Titanium has enjoyed nearly forty years of service in the CPI and can be considered a mature engineering material. Extensive technical literature and plant experience supports the fact that titanium offers exceptional value to the CPI engineers have discovered that titanium equipment can and does lower overall maintenance and downtime, and hence gives the lowest life-cycle costs for plant handling corrosive materials. This experience is spreading through the geothermal industry, with the use of Grade 29 well casing in the Salton Sea, USA, geothermal facility being an important example. This development may be very significant if it enables the use of sea water injection to augment depleted or low fluid aquifers, or to develop Hot Rock systems.

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THE DRYING OF FISH AND UTILIZATION OF GEOTHERMAL ENERGY - THE ICELANDIC EXPERIENCE -

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INTRODUCTION

In recent years, the annual world production of dried, unsalted fishery products has been 350,000 tones, but the total world production of dried fish is 3,140,000 tonnes. Production of stockfish is about 10,000 tonnes; the main producers being Iceland and Norway, the biggest producers of the other dried products are countries in Asia and Africa. The annual export of dried cod heads from Iceland are about 15,000 tonnes, mainly to Nigeria, where they are used for human consumption. Dried petfood is a new industrial production in Iceland and a growing industry, the annual production being about 500 tonnes. There has been much interest in Iceland in producing dried fish for human consumption from the various small fish species, like blue whiting and low fat capelin. The annual production of dried seaweed and kelp in Iceland is about 4,000 tonnes.

The use of geothermal energy in fish processing, instead of oil and electricity, has many advantages. In the fishing industry, geothermal energy has mainly been applied to indoor drying of salted fish, cod heads, small fish, stockfish and other products. The first companies in this field were founded 25 years ago and now there are more than twenty companies. Most companies use geothermal energy for drying codheads and collar bone. In 2001, the consumption of hot water was about 2 millions tonnes or about 550 TJ. Experiments have been done on the use of geothermal steam for fishmeal processing, but the company involved is no longer in business. It also seems to be possible to utilize geothermal steam for freeze-drying. There are unexplored possibilities in the utilization of geothermal energy in regions where there are good harbors located in geothermal areas.

Most of the research for drying in this field was done for about fifteen years ago. This time, the main work in these trials was to find out the best drying parameters to obtain the best products qualities and to optimize the drying processes. In the trials, the air speed, air temperature, air humidity, product loading on each tray and the size of the drying tunnel were determined. The latest trials on this field are to find out the influences raw materials has on the products qualities and the stabilization of the product with the difference storage parameters.

DRYING

Drying means that water is extracted from a substance, usually by heating. During drying, there are two things of primary importance, the heat transfer that causes the evaporation of water and the mass transfer of the evaporated water through the substance and subsequently the removal of moisture away from the surface of the substance itself. The main purpose in drying is to prolong the preservation time of the product. In short, deterioration of food is caused either by microorganisms or chemical processes. In drying, both of these processes are slowed down and finally stopped altogether, depending on how far the drying is carried out, with one exception, which is oxidation. The drying time is generally divided into two periods, period of constant drying rate and a period of falling drying rate. The former period is characterized by the surface of the substance being entirely saturated with moisture at the wet-bulb temperature of the air. The air velocity, temperature and the level of humidity control the drying rate. During the period of falling drying rate, the surface of the substance is already dry but the evaporation occurs inside the fish flesh. Now the air velocity has less effect and the speed of the drying process is mainly dependent upon the resistance against the water vapor flow to the surface of the substance. At the end, the drying process stops entirely and the moisture content of the fish at that point is called equilibrium humidity. Equilibrium humidity is primarily dependent on the degree of humidity of the air and to some extent on the temperature.

UTILIZATION OF GEOTHERMAL ENERGY FOR DRYING

In Iceland, indoor drying has been tested in regions where geothermal energy is to be found. The reason is that the cost of oil or electricity for heating of the drying air during the drying process is considerably higher than the cost of hot water or geothermal steam. It is, therefore, more cost-efficient to locate the processing near inexpensive hot water and steam sources and collect the raw material and transfer it to the processing plant.

The price of energy for heating varies much from one energy source to another and from one location to another. The price of oil has fluctuated but the price of hot water and electricity has changed less, although it tends to follow the price of oil. (See Figure 1).

Figure 1 shows the energy costs of heating air for drying one kilogram of dried cod head in Iceland. The prices are extrapolated using the price in January of 2003 and the main assumptions are that the energy required for evaporating one kilogram of water in the drying process from a substance is about 5,800 kJ (1,400 kcal), the efficiency of oil boilers is

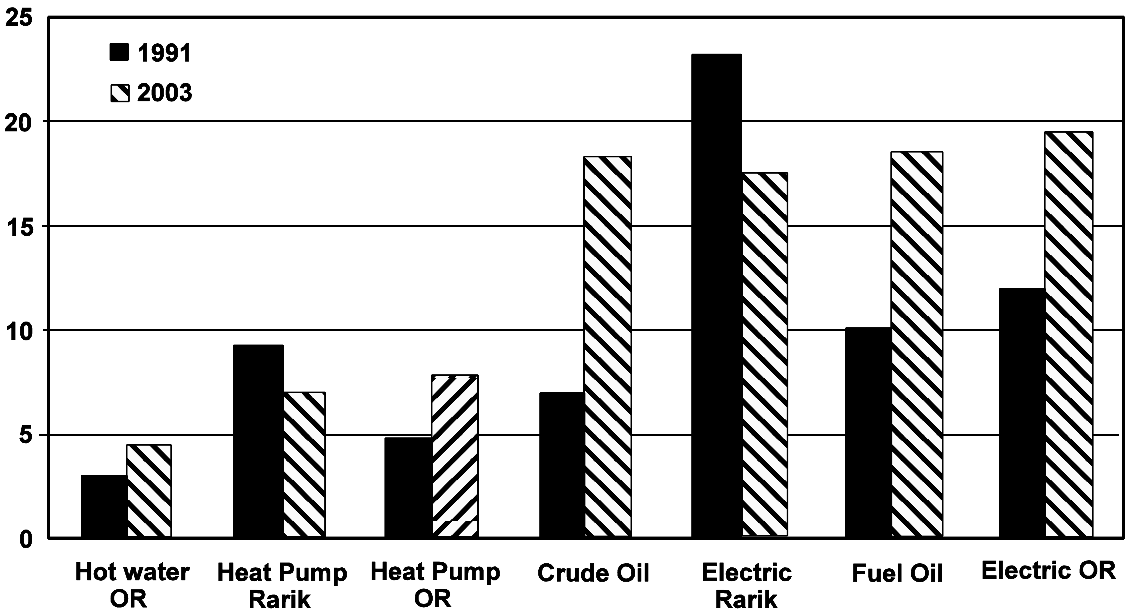

Figure 1. ***Comparison of prices for different types of energy for heating, ISK for drying one kilogram of dried cod head, based on cost in January 2003 (1 USD = 80 ISK). (OR= Reykjavik Energy and Rarik = Icelandic state electricity).***

estimated at 90%, coefficient of performance (COP) of heat pumps 2.5, and it is assumed that the hot water is cooled from 80ºC to 30ºC (Arason, 2001).

INDOOR DRYING OF FISH

Weather conditions put limits on outdoor drying in Iceland. Indoor drying of fish, such as cod-heads, or small fish, is done in such a way that hot air is blown over the fish and the moisture from the raw material subsequently removed. It is a great advantage to be able to dry fresh raw material all year around and not to be dependent on weather conditions. Furthermore, drying indoors takes much less time, from several weeks outdoors to a few days indoors. The main advantages of indoor drying are therefore (Arason, et al.,1982):

- Shorter drying time
- Drying all year around and regular export shipments
- The product is more consistent in quality and water content
- Flies and insects are prevented from contaminating the product
- Utilization of local energy sources

Traditionally, cod heads were dried by hanging them on outdoor stock racks (Photo 1), but 25 years ago, indoor drying was initiated. In Iceland, the production of dried cod heads increased from 1000 tonnes to about 12,000 tonnes annually and this production needs 60,000 tonnes of wet, fresh heads. The largest drying stations are Laugafiskur in Thingeyjarsysla, Samherji in Dalvik and Hnotskurn in Thorlakshöfn and Thorungavinnslan in Reykho1ar, which specializes in drying seaweed and kelp. In total, there are

Photo 1. ***Fish drying on an outside frame (taken in 1977).***

about 20 companies which produce air dried cod head, all of them except two using geothermal energy. One drying plant uses oil and another is using a heat pump system. A third one uses geothermal steam for drying but most companies use geothermal water. Most of the drying cabinets are constructed for batch drying and cod-heads are arranged on trays. Only two cod head drying plants and Thorungavinnslan use conveyor-belt dryers.

There are also about 50 small drying plants in Iceland which produce dried fish snacks, which are very popular in Iceland. Most of the small dryers are using geothermal energy.

Full drying of cod-heads indoors has been successful and the drying is divided into two stages, primary drying and secondary drying (Figure 2).

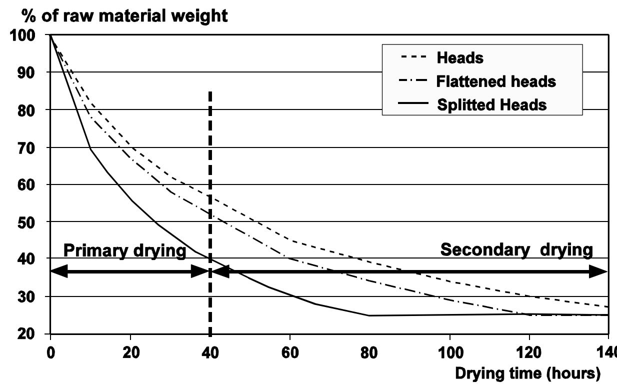

Figure 2. ***This figure shows how the weight of cod heads changes with time in indoor drying. The drying is conducted in two stages, primary drying and secondary drying. The cod heads are treated in three different ways prior to the drying.***

<u>Primary drying</u> is done in a rack cabinet or a conveyor-belt cabinet. The rack cabinet is the most common, with cod-heads arranged in one layer on the racks where about 25 kg of heads can be arranged per square meter (Photo 2). The optimal conditions of the drying air are: temperature should be 18-25°C, relative humidity 20-50% and air velocity about 3 m/s. The duration is about 24-40 hours (Arason, et al., 1992). The water content of the heads at the end of this stage is about 50-55%.

Photo 2. ***Employees placing fish heads on a rack.***

<u>Secondary drying</u> of semi-dried cod heads is conducted in drying containers of l-2m^3 volume with hot air blown through. The optimal conditions are: air temperature 22-26°C, humidity 20-50% and the air velocity in a full container is about 0.5-1 m/s. The water content of the cod-heads after drying is about 15%, or the product's water activity must be lower than 0.6, which is achieved in about 3 days in the drying container (Arason, et al., 1992) (Photo 3).

The greatest advantage gained by dividing the drying process is that relatively larger quantities of cod-heads can be placed in the secondary drying facilities than in the primary drying cabinets. The initial and operational costs of second-

Photo 3. ***Fish heads after drying.***

ary drying are much lower than that of primary drying so that the production cost is lower if the process is divided. In our experience, the best conditions for primary drying of cod head are as follows: air temperature at 25EC, airspeed about 3 m/s and air humidity about 45%. The final water content after the primary dryer is 55-60% (about 50%weight loss) and Figure 2 shows that it takes about 40 hours to reach that point (Arason and Benediktsson, 1988).

Figure 3 shows a complete flow diagram for the drying of cod heads, including yield figures. The total drying time for splitted cod heads is about 120 hours and the yield is 21.2%. For untreaded cod heads, the drying time is 160 hours.

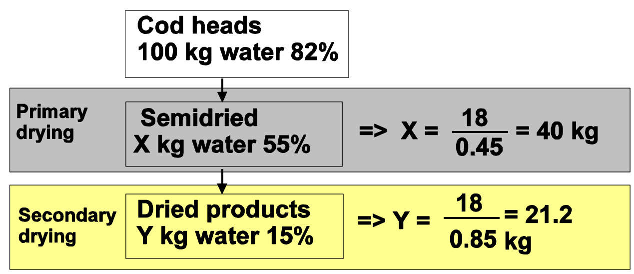

Figure 3. ***Flow diagram for the drying of cod heads. Percentage yield figures are given for each step.***

It is also possible to extract the heat from the drying air which is either blown out or recycled. The recycling of the heat is important, in particular in drying plants located outside of the geothermal regions. The results from a preliminary study at the IFL-laboratories indicates that it is possible to save up to 35% in energy by using heat-exchangers, and up to 70% through the use of heat-pumps (Arason, et al., 1992).

Chemical and microbiological tests show that there is no significant difference in the contents of stockfish, whether it is dried indoors or outdoors. There was, however, a great difference in the color where the indoor dried stockfish was much darker and kept its original color better than the stock fish that was dried outdoors. These tests showed that the total drying time for stockfish indoors is about 15-25 days. It is possible to shorten the drying time of outdoor drying by a few months by transferring it indoors for secondary drying.

DRYING SMALL PELAGIC FISH

The method of drying small pelagic (oceanic) fish is similar to drying cod heads, where the fish is first primary dried and subsequently processed through secondary step in drying containers. Only small, low-fatty fish, such as capelin and blue whiting caught at the time of the year when the fish contains less than 5% of fat, can be used for drying (Arason, et al., 1992). The fat content of capelin is less than 5% for about two weeks at the end of March, and therefore capelin intended for drying for the rest of the year must be stored. It is possible to store the capelin either be freezing or salting. In desalting, however, some of the dry material is lost, but the storage cost in salt is only one fifth to one third compared to that of freezing. Dried small fish is well suited for pet food as well as for human consumption.

The most important results regarding both blue whiting and capelin were that the fish should not be taken out of the drying cabinet (primary drying) unless the water ratio (weight of water/weight of dry matter) is down to 1.0 (50% w/w water content). Regarding the secondary drying, the fish can be taken out of the drying cabinet at a water ratio of 0.18 (15%). The temperature in the drying cabinet must not be higher than 30ºC. If it is higher, the fish will be cooked and become brittle and cannot be packed as whole fish (Jason, 1958). See Figure 4 for the drying curve for blue whiting.

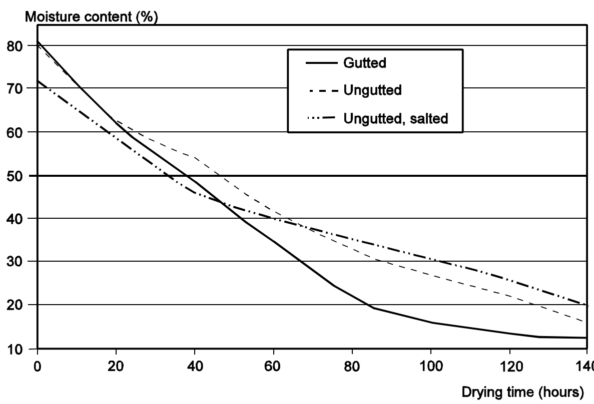

Figure 4. Drying curves for blue whiting.

Regarding blue whiting, the maximum total fat content for ungutted fish seems to be around 3.5%, if it is to be used for drying (Arason, et al., 1992). The fat content can vary considerably between individual fish (e.g., when measured in July it varied between 3-8% in the same catch). The reason for this is probably that blue whiting do not all migrate at the same time to the fishing grounds off the east coast of Iceland. Blue whiting must therefore be gutted prior to drying if it is caught later than in June.

Experiments were made with drying capelin in a rack dryer and a conveyor-dryer as primary drying. These experiments showed that the fat content in capelin should not be higher than 4.0% prior to drying (Arason, et al., 1992). According to this, the economical catching season is about one month in Icelandic waters. Mainly male capelin is used for the drying but the female fish can also be used after spawning, at which time they contain only 2% fat. The dried male fish is, however, considered to be of better quality.

Figure 5 shows the drying curves for capelin. The curves and the drying rate for frozen and fully desalted capelin are quite similar, but the curves for the semi-desalted fish are different because part of the water is bound to the remaining salt in the capelin. (Adolfsdottir and Arason, 1988).

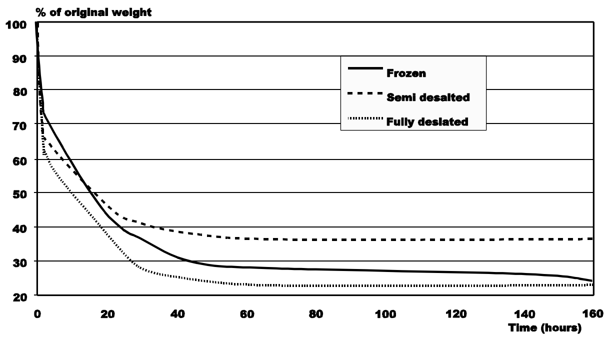

Figure 5. Drying curves for capelin. The capelin was frozen and salted before drying.

Figure 6 shows the drying isotherms for capelin. The isotherms for frozen and fully desalted capelin are quite similar. The water activity falls more rapidly when the water content is below 30% in the drying process. Water activity for semi-desalted capelin expectedly dropped more quickly and was about 0.7, with water content 35%.

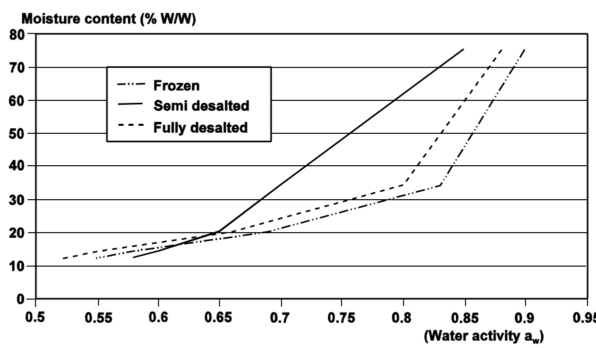

Figure 6. Relationship between moisture and water activity in dried capelin.

AIR DRYING EQUIPMENT

Batch Dryer - Rack Type

The most common equipment for indoor drying in Iceland is a rack cabinet (Photo 4), the cabinets most frequently consisting of two tunnels with a pyramid in the center). The pyramid can be moved in such a way that if the cabinet is only half full all the airflow is directed through one tunnel. Air-valves are inserted in the inlets and recycling outlets, but the regulation of the valves is controlled by the air humidity, measured at the opening of the cabinet. A regulating valve on the hot water inlet, connected to a thermometer, which is located at the same place as the humidity sensor, controls the temperature in the drying cabinet (Figure 7).

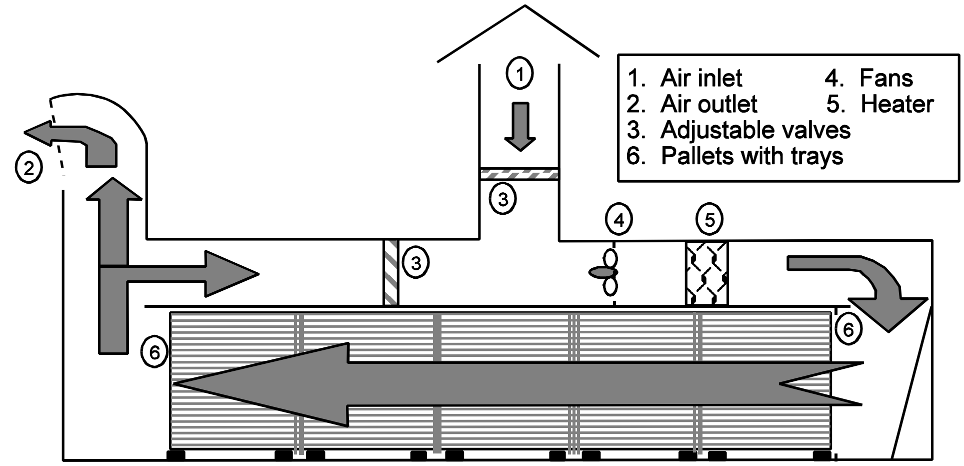

Figure 7. The construction of the rack drying cabinet.

Photo 4. Fish heads on rack cabinet.

One rack cabinet dryer with heat pumping system is in use in Iceland. The air is heated in the condenser and then blown through the cabinet. In the evaporator, the air is cooled and the moisture which was absorbed in the cabinet is condensed before the air is heated again in the condenser. About 40% of the energy needed for heating is supplied by electricity, but the other 60% comes through reuse of the condensing heat which is released in the evaporator (Arason, et al., 1992). The heat pump systems can be of use in warming where geothermal energy is not available. On the other hand, the initial capital cost is high and since there is not much experience with these types of cabinets, people have been hesitant to experiment with them.

Continues- Conveyor Belt Dryer

Three conveyor-belt dryers are in use in Iceland (Figure 8). They are located with the company Saesteinn and Thorungavinnslan. One of the conveyor belt dryers is used for primary drying of cod-heads and small fish, such as capelin and blue whiting, and the other one is used to dry seaweed and kelp. Initially, the wet raw material is placed on the top belt and then the belt is left idle for about 3 hours. After that, the product is moved down to the next belt and at the same time the first belt is refilled, etc. The two lowest belts are driven at half the speed of the three top ones so that the product stays for six hours on each belt. The raw material is therefore 20-24 hours in the cabinet and has then been reduced to about 60% of its original weight. The temperature in the cabinet is about 25ºC and the air velocity is about 2 m/s.

Secondary air drying

When fish is dried in rack cabinets or in conveyor-belt cabinets, it is removed from the cabinet when the water content has reached about 50-55%. The fish is then placed in a drying container of l-2m^3 volume (Arason, 2001). The container is located on top of an air tunnel duct and the air is blown up through it (Photo 5). It is possible to pile 3-4 containers on top of each other (Figure 9).

Photo 5. Secondary air-drying unit with geothermal pipes and controls on right.

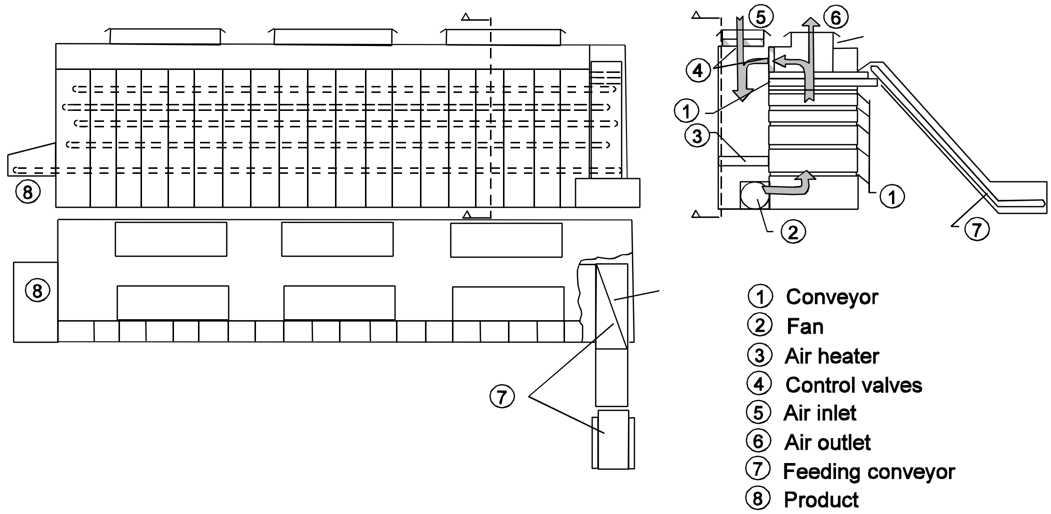

Figure 8. Continuous conveyor dryer for primary drying of cod heads.

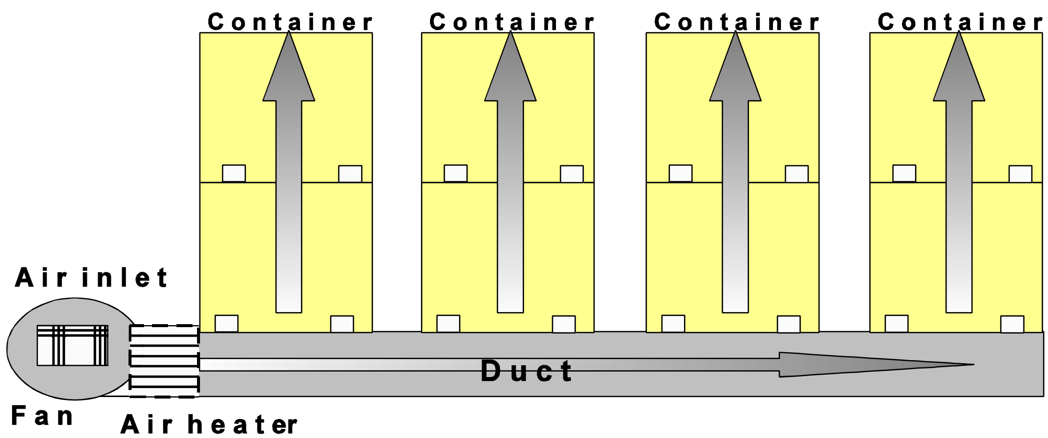

Figure 9. Secondary air drying unit.

ENERGY EFFICIENCY IN INDOOR DRYING

Naturally, the energy efficiency in drying cabinets depends on many different factors. It is generally measured through energy use per each kilogram of evaporated water. The latent heat of water at 20ºC is about 2,450 kJ/kg (585 kcal/kg), but in designing drying cabinets the figure 3,800 - 5,000 kJ/kg (900 - 1,200 kcal/kg) is most frequently used (Arason, 2001). The difference between these two numbers indicate a loss which can be divided into two types, conductivity and radiation losses on the one hand and thermal loss with the outlet air on the other. The conductivity and radiation losses are caused by the drying cabinet being warmer than the surroundings and the simplest way to reduce these losses is to insulate the cabinet. They are, however, so small that it is generally not considered worthwhile to do so. Heat loss through outlet air is dependent on the moisture content of the exhaust air. There are two ways by which the moisture content of the outlet air can be kept as high as possible. To make the cabinet very long or to recycle part of the air before it is let out. A very long cabinet has several disadvantages. It needs more space and the fish needs to be on movable carriages. Furthermore, there is more danger that the drying becomes more uneven and there is also the danger that the fish in the most humid air will dry so slowly that it will be spoiled. The use of energy of the blowers increases with added length of the drying cabinets, because of the increased resistance to the air flow. The length is therefore limited, because the use of electricity by the blower in most cases is more expensive than the heat that is used to warm the air. Therefore, it can be assumed that an increase in thermal efficiency of the drying cabinets through this method is an expensive alternative. It is, therefore, necessary to look at each individual case before action is taken, since it is difficult to come up with a general solution that is valid in all cases.

All the drying cabinets that have been constructed in Iceland have all been short, with automatic recycling of air. The thermal efficiency in these cabinets will never be as good as can be achieved in longer cabinets, but the initial cost is much lower because of a simpler and a smaller equipment. The thermal efficiency is greatly increased, compared with a cabinet where the air is blown through only once. In these automatically regulated cabinets, the energy use for evaporating the water is generally considered to be 3,800 - 5,000 kJ/kg (900-1,200 kcal/kg), compared with 5,400-6,600 kJ/kg (1,300-1,600 kcal/kg) before this technique was introduced.

One way to increase the energy efficiency in shorter cabinets could be to implement heat exchange in the air circulation. The heat exchanger would be utilized to pre-heat the inlet air, by cooling the outlet air and condensing the moisture at the same time. The main drawback of this would be the high expense of heat exchangers. Very large heat exchangers are required because of the small temperature difference between the cold and warm sides.

CONCLUSIONS

The use of geothermal energy for drying of fish and cod-heads is likely to increase in the future. The discussion is mainly focused on the use of geothermal energy in low-heat regions. The fishmeal industry is likely to use geothermal steam in the processing and hopefully within a few years, geothermal steam will be transported through pipes from Svartsengi to Grindavik, where many fish processing plants are located. It can be expected that the price of oil will increase more than the local energy in the future and, therefore, it is worth paying attention to the use of locally available energy sources for the fishing industry.

New, feasible alternative uses of geothermal energy are within sight, such as in freeze drying of food and one pilot project had analyzed that it is possible, it was recommended that further work on optimizing the technique and a feasibility study for a freeze drying production be done (Gudlaugsson,1998). Use of geothermal energy for drying is highly dependent on the price of crude oil and electricity and marketing prices of dried fish products. Equipment designed for drying fish can also be used for drying other industrial products.

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GRC 2004 ANNUAL MEETING

Plan now to submit your technical work for presentation and participation at the GRC 2004 Annual Meeting, on August 29 - September 1, 2004, at the Hyatt Grand Champions Resort near sunny Palm Springs, California. Through a special arrangement with the hotel, GRC room rates will be an affordable $109/night in first-rate accommodations at this truly splendid resort. The meeting will include the GRC's traditional Technical and Poster sessions, Opening Session, Annual Banquet, Workshops and Field Trips to nearby geothermal power operations such as Coso, the Salton Sea and Imperial Valley, and Cerro Prieto in Baja, Mexico. The 2004 Annual Meeting Committee will release information in the *GRC Bulletin* and on our website (www.geothermal.org) as planning progresses.

29th STANFORD WORKSHOP ON GEOTHERMAL RESERVOIR ENGINEERING

The Stanford University (Stanford, CA) Geothermal Program will convene its *29th Stanford Workshop on Geothermal Engineering* on January 26 - 28, 2004, at the Fisher Conference Center on the Stanford University campus.

The organizers strongly encourage all scientists and engineers involved in geothermal reservoir technology to attend the workshop.

Papers accepted for presentation and/or publication should be formatted to the finished specifications and returned as a camera-ready copy. The papers will be available as preprints at the Workshop and subsequently published in the Proceedings. For more information and Abstract Submission forms, visit the workshop website at http://ekofish.stanford,edu/geoth/workshop2004.htm.

Dates to Remember

October 10	Title and Abstracts due at Stanford
November 3	Notification of acceptance
December 28	Reservations at Sheraton for special rate
December 31	Reservations at Travelodge Hotel for special rate
January 10	Camera-ready copy and computer files due at Stanford.
January 26-28	Workshop convenes
February 20	Final camera-ready copy and computer files due at Stanford

WORLD GEOTHERMAL CONGRESS 2005

The *World Geothermal Congress 2005* (WGC2005) will be convened on April 24 - 29, 2005, at Antalya, Turkey. The event is a cooperative effort of the International Geothermal Association and the Turkish Geothermal Association. The national government of Turkey, along with several provincial and local governments, have offered support for the conference. Antalya is a major resort city with a population of over one-half million on Turkey's southern coast. The conference will feature pre-meeting field trips, short courses, a technical program of up to five days in length, a technical exhibition, and social/cultural programs. More information is available on the conference website at: www.wgc2005.org.

WGC2005 Call for Papers. Authors are invited to submit abstracts for WGC2005. Papers may be presented verbally or as posters. The official language of the event is English. Deadline for submission of abstracts is January 2004. Accepted papers must be submitted by May 2004. Papers will be reviewed, and if necessary, edited by November 2004. Note that only authors of accepted papers are eligible for financial support. All papers will be in English. Abstracts can be submitted online at: www.wgc2005.org/. They can also be faxed to Technical Program Chairman Prof. Roland N. Horne at: (650) 725-2099.