産学協同 시리즈

INDUSTRY & UNIVERSITY

國內低溫地下熱에너지 回收 및 活用

兪　亨　德

韓國科學院

(접수 1977. 7. 22)

Recovery & Utilization of Extreme Low Temperature Geothermal Energy in Korea

H. D. YOO

Korea Advanced Institute of Science, Seoul 131, *Korea*

(*Received July* 19, 1977)

要　約

低溫 地下 溫水 에너지(40～80°C) 活用을 爲하여 季節에 따라 空氣를 地下에 投入하는 方法을 研究하였으며, 地下 개스 貯藏庫 開發을 目的으로 하되 回收熱은 熱交換器없이 直接 地方에서 煖房에 使用 할것을 計劃하였다. 本案의 妥當性 檢討를 爲하여 豫備設計를 하였으며, 安全性, 經濟性, 埋藏量推算法, 地下水層內 移動性 等을 考慮하였다. 他回收 方途 및 電力發電도 簡單히 論하였다. 地下熱에너지 枯渴時는, 韓國에서 必要로 하는 經濟性 있는 少規模 地下 貯藏庫로 傳換을 하게 되며, 이러한 地下構造 活用은 熱 回收案을 成就시키는데 매우 重要한 條件이 된다.

Abstract

The recovery of low temperature geothermal energy (40～80°C) in Korea is investigated by injecting air seasonally for local community heating without heat exchangers, when a gas storage development is planned. A preliminary design was conducted to study the feasibility of the scheme. Safety, economics, reserve estimation, and aquifer dynamics were studied. Other recovery methods and power generation have been briefly reviewed. Conversion to a small gas storage system upon depletion of geothermal energy, because of the Korea's pressing need for underground storage system and the overall economic advantage, plays a very significant role to make the energy recovery attractive.

Introduction

Korea has about 20 hot or warm springs of which temperatures are in the range of 20～80°C. Some of these hot springs were known more than 10 centuries ago, and the aristocrats frequently visited for hot bath; even today these springs are better known as tourist resort areas (*Fig.* 1). Most of the springs have lost primary energy to overflow, and direct pumping of hot-water by air pressure has been practiced. The wells are stimulated and improved, and the average depth is about 700 feet. As yet very little or no information is available on the reserve capacities, nor has there been any industrial scale energy utilization attempt.

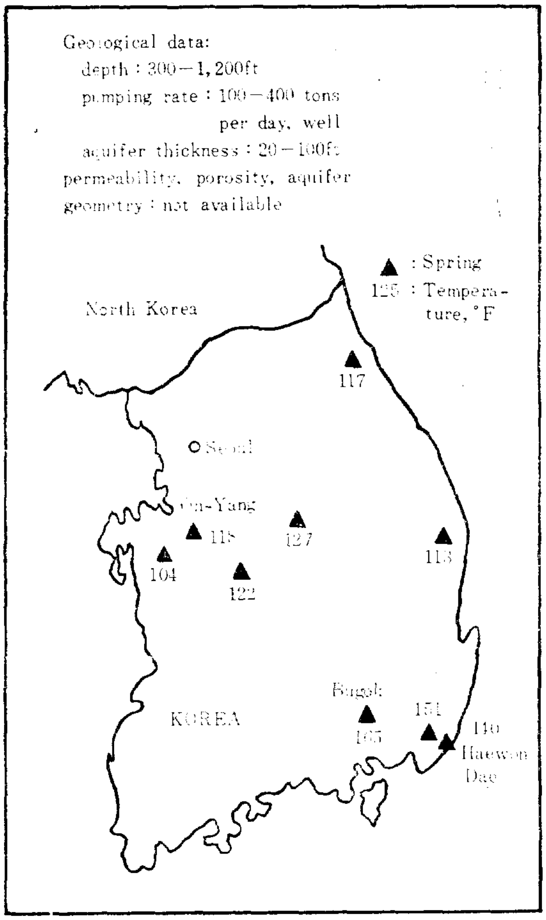

Fig. 1. Geothermal springs in Korea

The current objective of the study was originally to develop a better energy recovery method for better utilization from this primitive stage. This low level geothermal energy has long been ignored, but the 1973 energy crisis has changed the previous thoughts about this energy utilization and possible gas storage development. In order to improve the energy economics, it is felt that the heat exchangers have to be eliminated, and direct heating is proposed. The underground structure can be used as a large natural direct heat exchanger and gas storage, and air can be used as a heat transfer media. As to the air volume creation, one can take advantage of the aquifer dynamics which can years later be converted to a small gas storage after purging the air to a practical extent. In essence, this attempt relies on oil & gas production or aquifer storage principle as applied to low temperature shallow geothermal wells in Korea.

Recovery Methods

Numerous geothermal energy recovery methods are possible though the economics depends very heavily on the enthalpy level and the power requirement.

Some of the conceivable methods are:

a) Air injection recovery during gas storage development for direct home heating without heat exchangers. The compression, pipeline, well cost are expected to be very high, but the gas storage development requirement can offset the difficulties.

b) Direct pumping of hotwater, followed by direct heat exchange with air for direct home heating. This would be the simplest next stage development, only for energy utilization if the economics are competitive with coal heating.

c) Direct pumping & hotwater distribution.

This is one of the common practices elsewhere in the world where the enthalpy level is high enough (at times steam) to overcome the cost of transmission and surface heat exchangers at homes and buildings.

d) Pressure-vacuum recovery & hot air heating during gas storage development. Even though the actual recovery is done during small vacuum, high pressure cycle is necessary to create large heat transfer area to prevent excessive cold spot around the wellbore. This approach would be about equivalent to method a) except that it involves unsteady momentum, heat, and mass transfer simultaneously. Design and operation would be more difficult, and the utilization of low pressure air-steam mixture requires extra strenuous efforts. Compression and vacuum operations would of course be costly, but the air purging cost to get ready for gas storage conversion would be negligible compared to method a).

e) Air injection recovery & direct heating. Because of the enormous compression cost, this scheme is impractical for this low enthalpy level energy. It should be kept in mind that the process compressed air cost itself is already high, which is the economic limit in this case.

f) Direct pumping and binary cycle power generation. There seems to be no practice to generate power with this sort of low temperature energy, except a Russian plant (85°C, Freon binary fluid, R-2). The binary fluid has to be lower than C_4, and such an operation is considered economically risky at the moment where the turbine technology is very limitted.

Out of all these schemes, the first method seems to offer more promises in economic and operational success, and the following discussions will be directed toward this method.

Air Injection

From the very beginning of the work, the development of small gas storage system in Korea gave a strong incentive to study the air injection geothermal energy recovery method. Since the local communities rely very heavily on the coal heating, some how gas storage development plus air injection recovery project has to be justified. *Fig.* 2 shows an overall recovery scheme design. Compressed air injection is done during the summer to create gas pore volume in the aquifer and gets heated reasonably fast even without pressure perturbations, and the hot air is withdrawn during the winter, treated and distributed for direct space heating of hospitals, schools, and local government

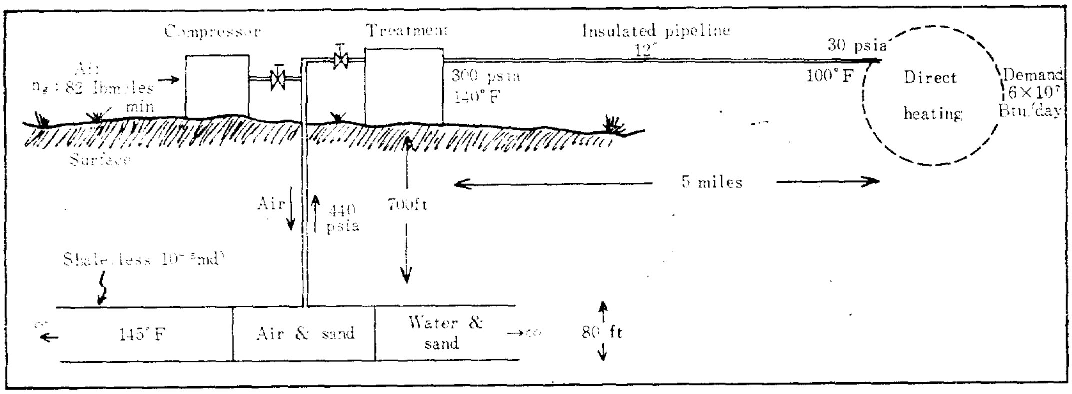

Fig. 2. Air injection recovery & utilization system design (during gas storage development)

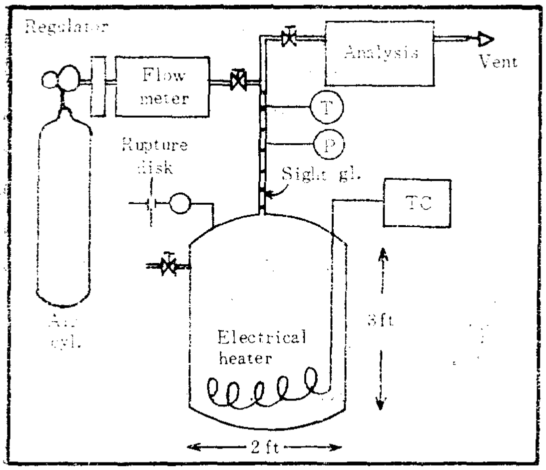

Fig. 3. Air injection recovery demonstration unit

buildings, etc. *Fig.* 3 shows the laboratory demonstration test how the method works, while the approximate gas pore volume variations are presented in *Fig.* 4, which would be adequate for the present purpose. The rigorous treatment calls a simultaneous solution of nonlinear partial differential equations describing material and heat balances with the moving boundary condition on a limitted aquifer geometry.

This solution is not known because of the limitted aquifer geometry and the nonisothermal condition (R-4, R-5). An approach is shown in *Fig.* 5 for an engineering solution. With this recovery method the assurance of aquifer storage development is seen because of the mathematical model confirmation during the few years of recovery operations. During this operation leakage of hotwater is possible, but this is rather advantageous for energy recovery point

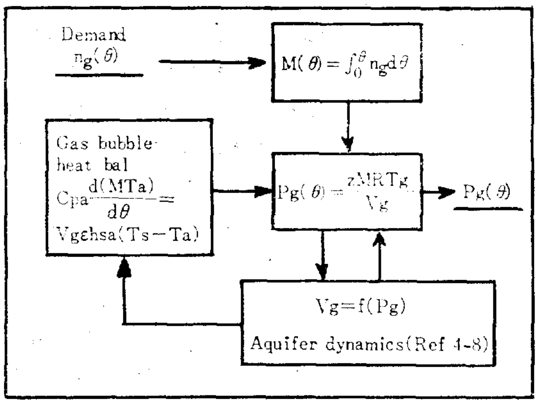

Fig. 5. Analog simulation (Appox. heat & material balance)

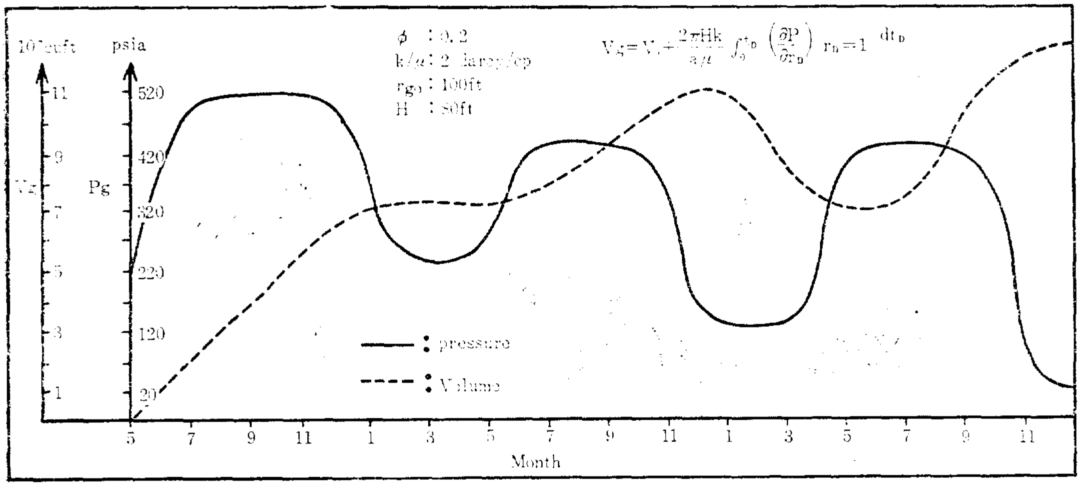

Fig. 4. Aquier pressure-volume variation

of view, and this would be a gas drive recovery essentially. When the system is to be converted, these identified leaks can be cemented permanently. Hotwater or air leakage is considered much less serious than hydrocarbon leakage during an aquifer storage operation which has been one of the big setbacks in the previous ventures in U. S. Since the well depth is shallow, the gas pressure has to be limitted, and the gas handling capability is also limitted, being a single well system, permitting only small scale gas storage development, which is still good enough in Korea. There are no depleted gas reservoirs in Korea nor there are sufficient particular underground geological data in that matter.

Heating Safety

The recovered hot air is to be treated precautionally for deodorization, desulfurization, dehumidification, etc. The air was tested for direct heating safety in the laboratory (*Fig.* 3), and from the spring hotwater analysis (*Table* 1), it was concluded that the hot air is adequate for direct heating even for the high sulfur geothermal springs in Korea. Of course, there are no appreciable CO or CO_2 as in the case of coal cake burning as practiced, in addition to the conveniences in small scale domestic use. Korea is experiencing a high CO poison death rate in these days.

Table 1. Chemical analysis of geothermal spring in korea.

Location	Haewondae	Onyang	Bugok
Temp. °F	142	118	172
PH	7. 3	8. 2	8. 8
Fe	0. 01	0. 01	
Al	0. 3	0. 0	
Cl^-	2, 731	32	14
F^-	0. 34	3. 22	2. 0
Br^-	3. 2	0. 0	0. 0
SO_4^{--}	450	45	74
K^+	21	1. 3	2. 0
Na^+	2, 133	56	110
Ca^{++}	615	17. 9	4. 0
Mg^{++}	8. 1	5. 5	
SiO_2			30
CO_2, free	11	0. 0	
H_2S	0. 0	0. 0	9. 0

(Units in ppm, R-3)

Reserve Estimation

The venture somewhat depends on the total energy reserve capacity since the invested equipment service life should be taken into consideration, and the energy supply capability has to be forecasted.

There are many geothermal reserve estimation methods adopted from the petroleum production geological, material or volumetric balance methods. A tracer material balance method is studied in the laboratory instead of heat balance method because of the heat loss in small equipment. *Fig.* 6 shows the equipment used for the tracer study while the transient response data are presented in *Fig.* 7 together with the estimated volume. It is hoped that a more generalized chart irrespective of geometry can be developed in the future. The difficulties encountered are the slow diffusion rate, and the

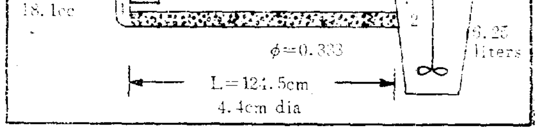

Fig. 6. Reserve estimation lab. equipment

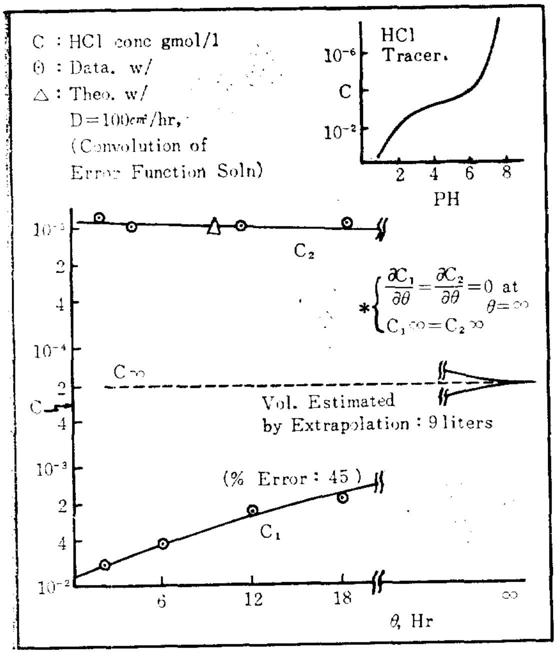

Fig. 7. Reserve estimation transient curves

initial condition of the reservoir which is difficult to identify. Anyway a conservative estimation can always be made. Interference study between multiple wells on a common aquifer, should these be available, should not be ignored to improve the estimation. The idea of the transient estimation method is that the different reserves give different transient response curves at large times as shown in *Fig.* 8.

It turns out that the reserve capacity does not really influence the economics seriously nor the decision making because of the pressing need for small gas storage system, other than to predict the optimum period of the energy supply and when to convert to a storage.

Economics

The economics of the air injection recovery depended mostly on the air compression, but if a gas storage is to be developed, then the only requirement of the geothermal energy is to be competitive with the domestic rural coal heating, as a by-product of a gas storage development project.

Since the process compressed air cost is high, this virtually rules out the possibilty of competing with coal as an independent energy source. In fact, it is intended to take advantage of the fact that an underground storage is the most economical way to store.

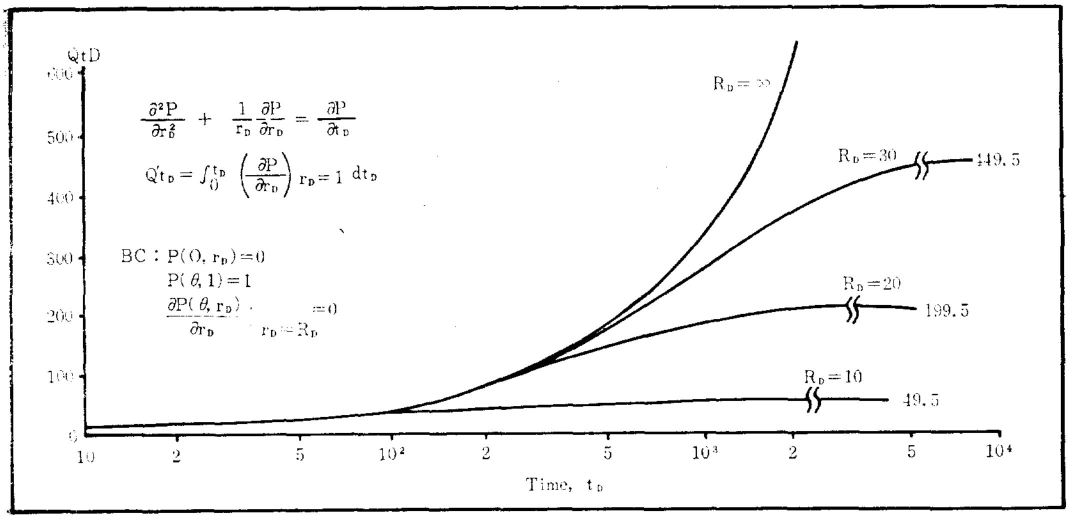

Fig. 8. Fixed boundary pressure case solution cumulative fluxfunction vs time

Table 2. Major costs in gas storage development.

Item	Cost, $
Investment (compressor, transmission system, well purchasing, insulation, air treatment)	1.5×10^6
Operating cost/yr (compressor power cost, depreciation & interest, mainte nance &repair, tax)	2.2×10^6
Income (byproduct geothermal energy)/yr	6.0×10^4
Gas storage development for 3 years	8×10^6
Subsurface frozen earth storage investment (Phillips Petro Co. data, 1963)	2.5×10^7

Table 3. Domestic energy cost comparison in Korea

Order	Type of energy	$/$10^6$ Btu utilized	Efficiency %
1	Domestic coal	8.2—12.3	40—60
3	Oil heating	8.4—15.1	50—90
4	LPG	13.9—18.9	70—95
5	Electrical heating	17.6—19.5	90—100
2	By-product geothermal energy during gas storage development	10.0*	100

*Table 2. (February, 1977)

Table 2 shows the summary of the economic study for geothermal energy by air injection gas storage development while *Table* 3 gives a rough cost guidelines of different energies in Korea. These indicate that the geothermal energy recovered by air injection on route of gas storage development has a good possibility to substitute domestic coal burning.

Conclusion

The recovery of low temperature geothermal ergy (40~80°C) in Korea by summer air njection for direct local community winter heating is feasible, only if the energy recovery is a by-product of a small aquifer gas storage development project.

Then this safe convenient clean energy can replace the cheapest rural energy-coal heating. As an independent energy recovery project, the air injection recovery method is not economical because of the high compression and transmission cost, as high as the process compressed air cost. Air injection recovery of geothermal energy for gas storage development is a project to be considered to help solving the energy problems in Pacific Asia.

Acknowledgement

This work was supported by the KAIS research fund. Graduate students S. C. Shin and H. W. Ryu were actively participated in preparing the final manuscript.

Nomenclature

a: Time constant defined as $a=\frac{k}{\phi_c \mu \gamma_g^2}$, 1/month

C: Concentration; C_∞, equil. concentration, lb-moles/cu ft

c: Compressibility of geowater, 1/atm

C_{pa}: Heat capacity of air, But/lb-mole°F

D : Diffusivity, ft^2/hr

h_{sa} : Heat transfer coefficient between sand & air, But/hr $ft^{2\circ}F$

H : aquifer sand thickeness, ft

k : Permeability, darcy

L : Packed tube length, ft

M : Moles of air, lb-mole

n_g : Flow rate of air, lb-mole/hr

P_g : Pressure; P_{go}, discovery pressure of aquifer, lb/in^2

Q_{tD}: Dimensionless cumulative flux function, constant pressure case

r_g : Radius; r_{go}, initial gas bubble radius, ft

r_D : Dimensionless radius defined as r_g/r_{go}

R_D : Dimensionless radius of aquifer size

R : Gas constant, atm cu ft/lb-mole°R

T : Temperature; T_s, aquifer temperature; T_a, air temperature, °F

t_D : Dimensionless time defined as $t_D=a\theta$

V_g : Gas volume; V_{go}, initial reservoir pore volume; V_t, tank volume, cu ft

x: Axial distance, ft

z: Compressibility of gas

ϵ: Surface/unit volume of sand, 1/ft

θ: Actual time, month

μ: Viscosity, centipoise

ϕ: Porosity

References

1. Geol & Mineral Insti of Korea, "Thermal sperings in Korea," MOST Report, 1976.
2. D.H., Cortez, Ben Holt and A. J. L., Hutchinson, "Advanced Binary Cycles for Geothermal Power Generation," *Energy Sources* **1**, No. 1 (1973), 7.3
3. M. Y. Yang, "Chemical Analysis of Hot Springs in Korea, *Bulletion Geol Survey Korea* **401** (1973).
4. H. D., Yoo, "Analog Simulation of a Radial Flow Moving Boundary Problem," *AIChE* Symposium Series **58**, No. 37 (1962), 75.
5. H. D., Yoo, D. L., Katz and M. R., Tek, "Study of Gas storage Reservoirs Subject to Water Drive on Electronic Differential Analyzer" *AIME-SPE* Journal, No. 12 (1961), 287.
6. H. D., Yoo, "Plan for Hydrocarbon Underground Storage in Korea," 4th Intl Technical Conf., KNAS, Seoul, 1976.
7, D. L., Katz, et al, "*Underground Storage of Natural Gas*" Summer Session, University of Michigan, 1959.
8. W., Hurst, and A. F., Van Everdingen, "The application of Laplace Transformation to Flow Problems in Reservoirs," *AIME Petro Trans.*, **186** (1949), 305.
9. F., Emde, and E., Jahnke, "*Tables of Functions*," Dover Publications, N. Y., 1945
10. S. S., Einarsson, "Geothermal Space Heating & Cooling," Proc. 2nd U. N. Symposium, **3**, 1975.
11. J. F., Kunze, et al, "Noneletcric Utilization Project, Boise, Idaho," Proc. 2nd U. N. Symposium, **3**, 1975.
12. H. S., Carslaw and J. C., Jaeger, "*Conduction*" *of Heat in Solids*, 2nd ed. Clarendon Press, Oxford, 1959.
13. C. J., Geankoplis, "*Mass Transport Phenomena*," Holt, Rinehart & Winston, N. Y., 1972.
14. J., Crank, "*The Mathematics of Diffusion*," Clarendon Press, Oxford, 1970.