Proceedings of the 4th African Rift Geothermal Conference
Nairobi, Kenya, 21-23 November 2012

Anthology of Geothermal Power Plants Efficiency: Energy Recovery and Water Condensate Recovery

Hugo Fernando Navas

eems international®, ,8 calle 17-15 Zona 15 Colonia El Maestro 2, Guatemala City, GUATEMALA

hfnavas_lion@yahoo.com

Keywords: Energy factors and conversions MWe, MWh, t/h to kg/s, enthalpy kJ/kg to KWh/t, energy balance, energy recovery, steam condensate mass loss, 4 areas of a modern geothermal power plant.

ABSTRACT

This work is titled "Anthology" for being a compendium of selected concepts related to a geothermal energy power plant, and ultimately its operating efficiency.

First, before discussion of the concepts, methods, and technologies of "energy recovery" there must be a clear consciousness of the "total energy balance" involved in the energy conversion processes of a geothermal power plant.

For example, as shown in Table 1 below the total energy is distributed through several surface processes. To generate 100 MWe, the total energy carried by the geothermal fluid produced is in the order of 850 MWh of thermal energy.

Table 1: Example of a traditional design total energy balance

Process Description	MWh	%
Geothermal fluid produced from wells	**850**	**100**
Separated steam, **60 % mass**	700	83
Separated brine, **40 % mass**	150	17
Transmission + transportation loses	125	15
Separation + **venting** + other losses	50	6
Vacuum system ejectors	35	4
Plant inlet to turbine – generator	500	60
Plant outlet to condenser	425	50
Cooling system, **70% of steam mass is lost** to ambient with conventional cooling	400	45
Delivery to National grid 100 MWe	**100**	**12**

Therefore to produce 1,000 MWe the surface energy extracted from the geothermal field is 8.5 GWh, every hour.

Keep this ratio in mind. - usually a hidden/obscure fact.

Secondly, for purposes of clarity, unification, and better communication – for the geographical geothermal field and power plant - there should also be in place a modern geothermal power plant, design / planning / organizational concept, in 4 areas. There is need to have a common field and plant concept. This is just as important as having a units system. A geothermal power plant can be defined as 4 areas:

A1. Reservoir + wells for production or reinjection + steam gathering + separation + transportation + venting.

A2. Energy conversion plant: turbine + generator + condenser + vacuum + cooling system + pumps + fans.

A3. Electric yard / delivery to grid: Substation + transformer + tower + meter.

A4. Control room + auxiliaries. Operators control + maximize production.

Thirdly, there is need to adopt the P h chart to modern geothermal terms. When Richard Mollier, in late 1800s deduced his enthalpy concept, the units and charts; he was probably thinking of fueled steam boilers conditions of water, not geothermal power plants. To adapt this to modern geothermal terms the unit of h: [kJ/kg] can be expressed as [KWh/t] - an obvious convenience in geothermal terms.

Fourthly,, the quantity of wasted condensate water in the traditional cooling system, is 70% of the separated steam mass (5.6 t/MWe) which is unacceptable owing to the fact that EAR countries are dry zones and need this water.

5.6 x 8,400 h/yr x 30 yr = **1.4 million m^3 / MWe**
700 million m3 / **500 MWe**. (= Lake Naivasha)
1,400 million m3 / **1,000 MWe**.

This is a lot of water lost with no benefit. Isn't it? It would rather be used for drilling + reinjection for reservoir sustainability + other direct uses.

Now, with this background we can think about and tackle the issues of where and how to achieve efficiency. How to recover some wasted energy, how to recover wasted water condensate, economically, and sustainably while making money at the same time. **WIN WIN WIN.**

There are developed methods and technologies to recover some lost energy (4 – 10%), and others to recover the lost steam condensate water (up to all the lost condensate).

1. INTRODUCTION

There are few works, related to overall geothermal power plant efficiency and how to enhance it. But the actual situation is that, and most of the thermal energy produced on the surface from the geothermal fluids goes to waste. However if we study and understand the processes, it can be improved. Efficiency is Profitable.

Energy recovery requires some planning, execution and minor modifications. It is an economical way of producing more MWe and making money.

Steam condensate water recovery requires some planning and execution. Specific A2 system components may be upgraded, modified, or replaced; value of water defined and a suitable technology selected.

2. TOTAL ENERGY BALANCE

As already stated, it is important to keep the overall energy picture in mind, since the subject of a geothermal energy power plant is energy - before during and after all its conversions. The practical ratio for condensing power plants is 850 MWh thermal to 100 MWe.

Step one: Prepare a study to know the overall efficiency, and have an energy balance of the actual conditions of a specific geothermal power plant.

MWh total + MWe + % efficiency

Then work from there up to higher economic efficiency.

If a condensing power plant has 12% operating efficiency, it is possible to increase it to **14 %**. Energy Recovery is economical, with minor modifications in the plant, no drilling, no new wells. It basically involves using the energy on the surface better than initially designed.

2.1 Practical Limit of Energy Recovery

It is reasonable to expect an energy recovery plan to range from 2 – 10 % of the total energy, depending on the present efficiency and identified sources of wasted energy.

Some of the energy used / not used on the surface is an inevitably high % of the total, but it is good to know exactly where, when, and why.

2.1.1 Transmission Losses:
It is inevitable to have some cost or loss, due to transportation of energy from one point to another. In a geothermal power plant it is common to have several km of steam pipe lines going from wells to the power plants, after steam separation. 35km of steam pipe lines in each geothermal field of about 150 MWe can be normal.

Careful design and actual evaluation are important to know how much of the total energy is lost before it reaches the conversion plant. The design may have it as a “traditional factor” of 10%, but in reality it may be higher than 15 %, or half more than designed and expected. The energy loss from transportation cannot be recovered but it should be efficiently designed, built, and known. Avoid sharp 90° elbows, avoid orifices, avoid leaks, etc.

2.1.2 Separated Brine:
It can carry from 15–50% of the produced energy. Therefore some consideration has to be given to this as an energy carrier in liquid form, and if some of its energy can be used. Brine can be used for electricity production, drilling or a number of direct uses, before being reinjected.

There are available technologies to recover the brine energy. Since this is comparably at much lower enthalpy than steam, brine is called a low enthalpy energy source.

2.1.3 Some of the Recovered Energy can become MWe.
If prioritized, some saved MWh can be directly converted to MWe, either by using the existing power plant equipment or by using a lower enthalpy energy conversion system.

Specifically the energy from separated brine,can become the source of second flash steam or it can be used as heat source for a binary system. The first option is more economical than the ORC, since it involves no additional equipment - the same power plant is used for the conversion. The second option of using the hot fluid for an ORC binary system, involves adding a new plant, with characteristics of taking the energy from a low enthalpy source, and therefore requires a large flow, and is of less efficiency.

Since hot water, at the same pressure and temperature as steam, has about 3 times less energy, or enthalpy, the efficiency of the converting system, will be conversely 3 times less than that for the binary ORC. For example a condensing turbine is 18% efficient, while an ORC binary may well be operating at 6%.
2.1.4 Steam Venting and Ejectors for Vacuum
These are the modern equivalents of bleeding patients. Such practices can be avoided with more controls and better design. They may be acceptable if used as emergency measures and procedures, but not as continuous daily operational ones.
Know your energy balance, efficiency, and keep walking.

3. INNOVATION IS THE KEY TO EFFICIENCY

The key to competitiveness for any economy in the world is knowledge, and that means R&D for innovations.

4. FOUR AREAS OF MODERN GEOTHERMAL POWER PLANT ORGANIZATION

There are 4 defined areas in a modern geothermal power plant. A person can only be in one at a time. There are human specialists for each area. The O&M manager of a power plant is the director of all other groups. A modern geothermal power plant concept is useful for designing / planning / operations organizational concept. The four areas are:

- **A1** — **Reservoir + Field**: gathering production + separation + venting transportation + reinjection
- **A2** — **Energy conversion plant**, turbine + generator + condenser + vacuum + cooling system + pumps + fans
- **A3** — **Electric yard** / delivery to grid. Substation + transformer + tower + meter
- **A4** — **Control room + auxiliaries**. Operators control + maximize production

In addition to O&M there is a Monitoring & Evaluation

(M&E) operation. M&E reports the results, deviations and proposed solutions. This is a management tool for power plant optimization.

5. LOG P VRS h – PSYCHROMETRIC CHART FOR GEOTHERMAL USES

The psychrometric charts describe the field of engineering concerned with the determination of physical and thermodynamic properties of vapor mixtures. It shows in a single chart all physical conditions: P, T, density, enthalpy and entropy.
Steam + brine mixture is precisely the case of geothermal fluids when reaching the surface, in most cases. This is then directed to near or far steam and brine geothermal flow separators.

> Any geothermal fluid process, and its related energy - starting from meteoric rain thousands of years ago, to its heating, while reaching depth, reservoir conditions, later extraction by well casing, surface conditions, separation, transport to electric conversion plant, and ambient release by use of cooling tower - can all be shown in a single chart with geothermal units – log P vs h.

It is an incredible, useful and economic tool. It is different from other forms of modeling, like conceptual, or mathematical, or computer aided, and other much costlier options.

The log P h chart for surface geothermal conditions, is presented in Figures 1 and 2. The chart is a selected section of mixture with enthalpy h unit modification of the Mollier log P versus h chart.

6. WASTED STEAM CONDENSATE WATER

The quantity of steam condensate water that is traditionally lost to ambient using cooling tower technology, as cooling system, is by design **about 5.6 t/MWe**, every hour. Geothermal steam water condensate may have little or no value, when in an island, where they are surrounded by it, for example, in Japan, Iceland, Indonesia, Philippines, etc.

Since the inception of the first generation of geothermal power plants, cooling tower technology became acceptable in most cases, even in drier or drought prone latitudes. In light of the experience gained in ARGeo countries and other locations during the past decades, it is now time to review and reconsider this before building new plants,

Steam condensate water is very valuable:

1 MWe loses	**1.4 million m3** of water.
1,000 MWe lose	**1,400 million m3** of water.

As shown above, the large amount of water alone is a clear reason to modify existing plants and change design of new ones.

Steam condensate water can be used further instead of evaporating it into the cooling tower plumes. It can be used for reinjection, drilling programs, and other valuable direct uses – like food growth. Furthermore more its value in terms of $/m3, makes a case for its recovery and sustainability.

An important lesson learnt in the past decades is that water is the only “transporter” of geothermal energy that is needed in a sustainable cycle, as reinjection, to go down and grab more energy to bring to the surface for electric conversion, and back down again. Many known geothermal places go to great distances to get more reinjection flow up to 100% of production or more.

A second option is to put a value to water condensate $/m3. 3, 5, 10? If produced from sea it will cost about $20/m3.
A third way is to see the benefit of reinjection, since it will directly affect the reservoir pressure, for sustained production in the long-run.

After these considerations, are seriously made, then decide if other non-evaporative cooling technologies, such as plumes can to be chosen. Even if the initial cost is higher, it becomes a marginal issue, compared to the larger benefit. (See the references for an e-link for water recovery technology, already used at plants with hundreds of MWe).

All energy conversion systems need cooling. However, there is a misunderstood apparent benefit of evaporating water to ambient and saving some KWh, while the steam water condensate could be better saved and re-used for a long time. In some countries, like UK, and perhaps others, the steam water plumes of cooling towers are forbidden by law.

In Kenya, the binary plants, in Olkaria, 50MWe + 50MWe and the thermal plants in Kipevu, 120MWe have a cooling system that could be but is non evaporative.

> **Step two**: Prepare a study to know the amount of water that is being lost to ambient, from the steam condensate, by cooling system.
>
> Range from **5.6 – 8.5 t/h per MWe**.

7. GEOTHERMAL ENERGY ECONOMIC FACTS - IN TERMS OF COST / BENEFIT

It has been shown that a geothermal well of 5MWe capacity, with an initial commercial cost of 6.5 M$, can last for 30 years, if reservoir pressure is well sustained. It is also a lot more economical than using a diesel engine generator that will consume more than 7.5 M$ / year of fuel to operate and produce the same electric energy of 5MWe.

> Comparison of **heat source** cost favor geothermal **35:1**.

Including O&M

Diesel engine fuel alone conversion is about 546 KWe/bbl.
At 110 $/bbl the fuel cost per 1 MWe + O&M.

$$\frac{(1.83\, bbl)(110)\$}{bbl\ MWe} + \frac{15\$}{MWe} = \mathbf{215\$/MWe}$$

Geothermal well including O&M, the cost in 30 years for a well head unit per MWe.

$$\frac{6.5M\$}{(30)(8000)} + \frac{6.6\$}{MWe} = \mathbf{12\$/MWe}$$

Comparison factor remains in favor of geothermal **18:1**

Geothermal Energy Recovery
Energy recovery has a more dramatic cost/benefit analysis - better than the above reviewed facts of the already clear cost/benefits of geothermal energy compared to other sources.

The plan to do geothermal energy recovery has a cost and benefit, in $ terms, during 30 years. Instead of wasting the energy, doing a controlled second flash steam recovery for 1 MWe, or 8 t/h, it has a cost of about 250K$. While the benefit, for a low 90 $/MWe, is 21.6M$.

$$\frac{Cost}{Benefit}(1\,MWe) = \frac{0.25}{21.6}$$

Cost Benefit of **geothermal energy recovery** up to **86:1**

That is a ROI of about 288% per year.

8. CONCLUSIONS

- With results of sections 2-7, above, for the ARGeo geothermal field of your choice, you have the basic inputs required to estimate and prepare the following:

+ Plan to recover energy, based on a study that will calculate total MWh, and with MWe actual production, calculate the actual efficiency %. + Recovery plan to save steam water condensate, based on a study will determine the present steam mass losses to ambient in total t/h. + Increase overall efficiency %. + Make money in the process.

- Geothermal efficiency is profitable: The Value of the investment cost /benefit can be overall up to 50:1.
- Steam water condensate saving is better than if released to the atmosphere. In $/m3 terms, or in pressure sustainability terms, or in reinjection cycle terms, et al.
- Research & development is the solution to innovative ways of being more competitive, efficient and adding value.

REFERENCES

GEA Power cooling Systems: GEA Power Cooling, with over 30 years experience, incorporates leading technology and lifetime customer support in its wet and dry cooling solutions, providing superior performance and years of cost effective service with minimal maintenance requirements.
Dry Cooling Solutions
• Air-Cooled Condenser (ACC)
• Parallel Condensing Systems
http://www.geapowercooling.com/opencms/opencms/gpc/en/products/Air_Cooled_Condensers/

Ngure, S., KenGen: Strategic Role of Legal & Regulatory Environment, ICS Core Program on Geothermal Energy, Decision Makers' Workshop on Geothermal Energy ICS-UNIDO, June, Addis Ababa, Ethiopia, (2009).

Knowledge is the currency of the future economy. EU Research, Innovation, and Science Commissioner, 2012. Innovation comes from R&D.
http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/12/537&format=HTML&aged=0&language=EN&guiLanguage=en

Navas, H.F. courses, conferences, papers, and presentations, at several venues, in 4 Continents:
 Course on Geothermics, ICTP, Trieste, Italia. “Modern Administration of Geothermal Plants”
 Workshop on Geothermal Innovations, ICTP, Trieste, Italia. “Geothermal Separators”
 Seminar in Addis-Ababa, Ethiopia. “How to save a decade in Geothermal Developments”
 Conference in New Delhi, India. “Efficient System for Geothermal Steam Separation”.
 Conference in Kyushu, Japan. “Monitoring & Evaluation for Managers of Geothermal Power Plants”

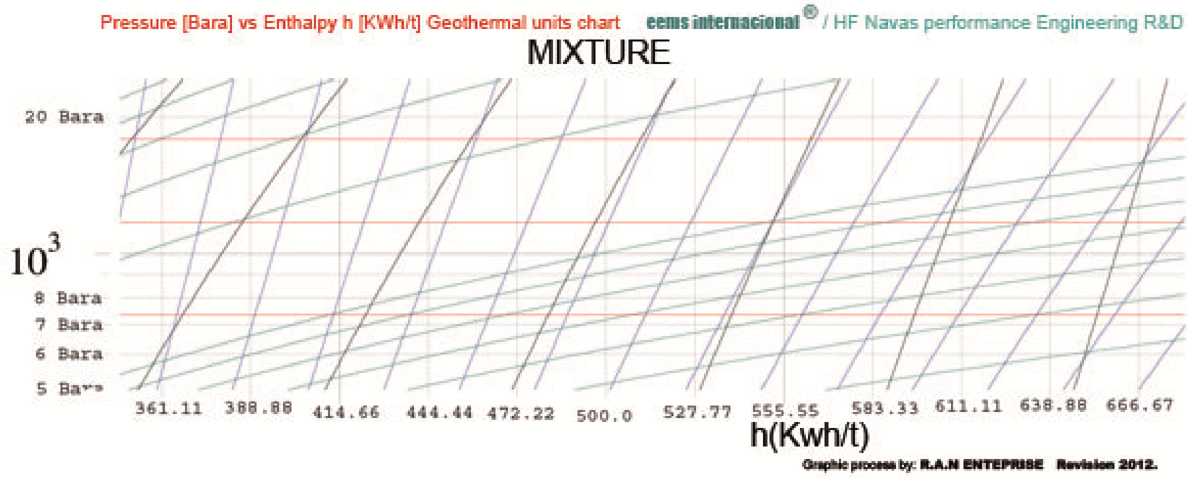

Figure 1: Log P {bara} h[KWh/t] psychrometric chart – geothermal conditions reached at surface before separation.

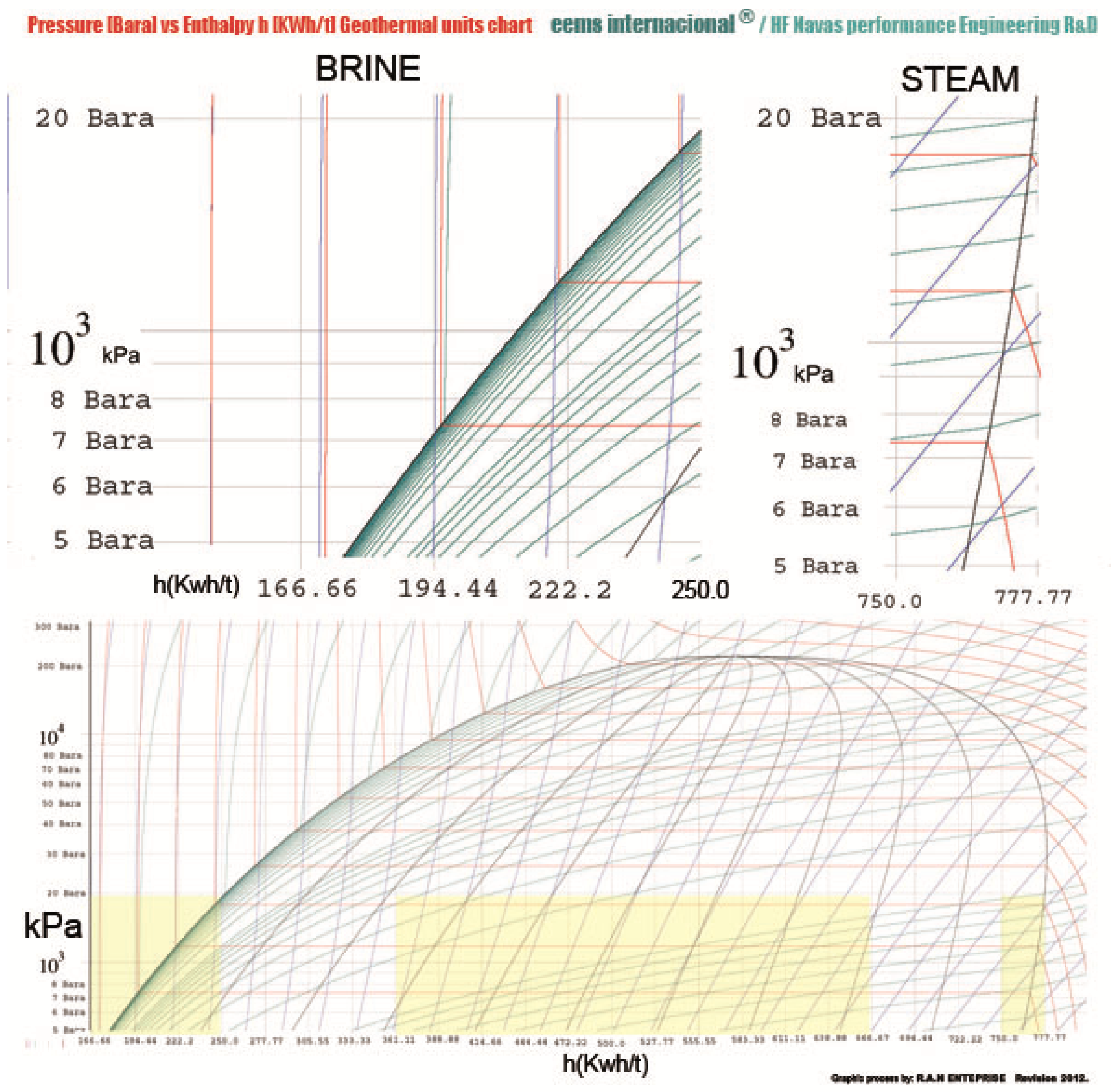

Figure 2: Log P {bara} h[KWh/t] psychrometric chart – geothermal conditions after separation: Brine + Steam + full curve