The Potential of Oil and Gas / Geothermal Co-Production in Florida

Robert D. Hunt[1]
Linear Power, Ltd. Beach, MS 39560 USA

Keywords: geothermal, gas-lift, total flow, thermal efficiency, gravity, water density, thermodynamics

Abstract

RenewableOne is planning an Oil and Gas / Geothermal Co-Production Plant to be located in Santa Rosa County, Florida using a novel total flow, closed gas-lift cycle licensed from Linear Power, Ltd. in order to generate substantial power from kinetic energy as it produces water from old oil and gas wells that still contain residual amounts of hydrocarbons remaining in the reservoir. Normally, pumping water from the wells would use power instead of gaining power. Then additional geothermal power is planned to be generated using conventional binary systems for much greater overall power output. Among other incentives, a new Federal Law provides that oil and gas produced in association with geothermal power generation is tax free. While oil and gas geothermal co-production is generally associated with Louisiana and Texas, Florida has a great potential to exploit its deep heat power without the need to drill wells that dramatically reduce the costs and risks involved in the enterprise. The power generated is planned to be used by a nearby new clean energy park being built by RenewableOne in order to power the manufacture of renewable energy devices with geothermal energy produced by the old oil and gas wells. Many other sites in Florida have the potential for oil and gas / geothermal co-production.

Introduction

This document describes an oil and gas kinetic energy harnessing positive displacement free-piston engine being developed in the Houston / Galveston region of Texas for the oil and gas industry that is evaluated for its potential for oil and gas / geothermal co-production in Florida. At the outset, the free-piston kinetic engine was specifically designed to handle high pressure, corrosive brine produced by geopressure wells, even at extreme pressures exceeding ten thousand pounds (10,000 psi) per inch (68.9 Mpa). However, many oil and gas wells do not possess geopressure; therefore, a process to create artificial geopressure was developed using gas-lift technology capable of being powered by conventional power cycles in order to drive the kinetic engine.

[1] Linear Power, Ltd., 6082 Espy Avenue, Long Beach, MS 39560 USA; Telephone (228) 363-0736, hunt0972@bellsouth.net, www.freepistonengine.net

The South Texas project is being led by the Houston Advanced Research Center (HARC) based on theoretical thermodynamic work performed by Linear Power, Ltd.'s Chief Scientist Robert D. Hunt the author of this paper. The initial test conclusions from the pilot project are planned to be presented during the GRC 2011 Annual Meeting in San Diego, CA.

Technology Description

The herein described power cycle driven gas-lift process is an adaptation of the "total flow cycle" whereby a total high pressure flow of both gases and liquids drives a prime mover, which in this case is a positive displacement free-piston engine. The original process was described using a high temperature geothermal well that flashed water to steam to produce gas. The system described herein is designed to beneficially use lower temperature water that is not generally hot enough to generate steam. Therefore, low-boiling-point liquids are used as working fluids that are capable of producing high vapor pressure gases from much lower temperature heat sources.

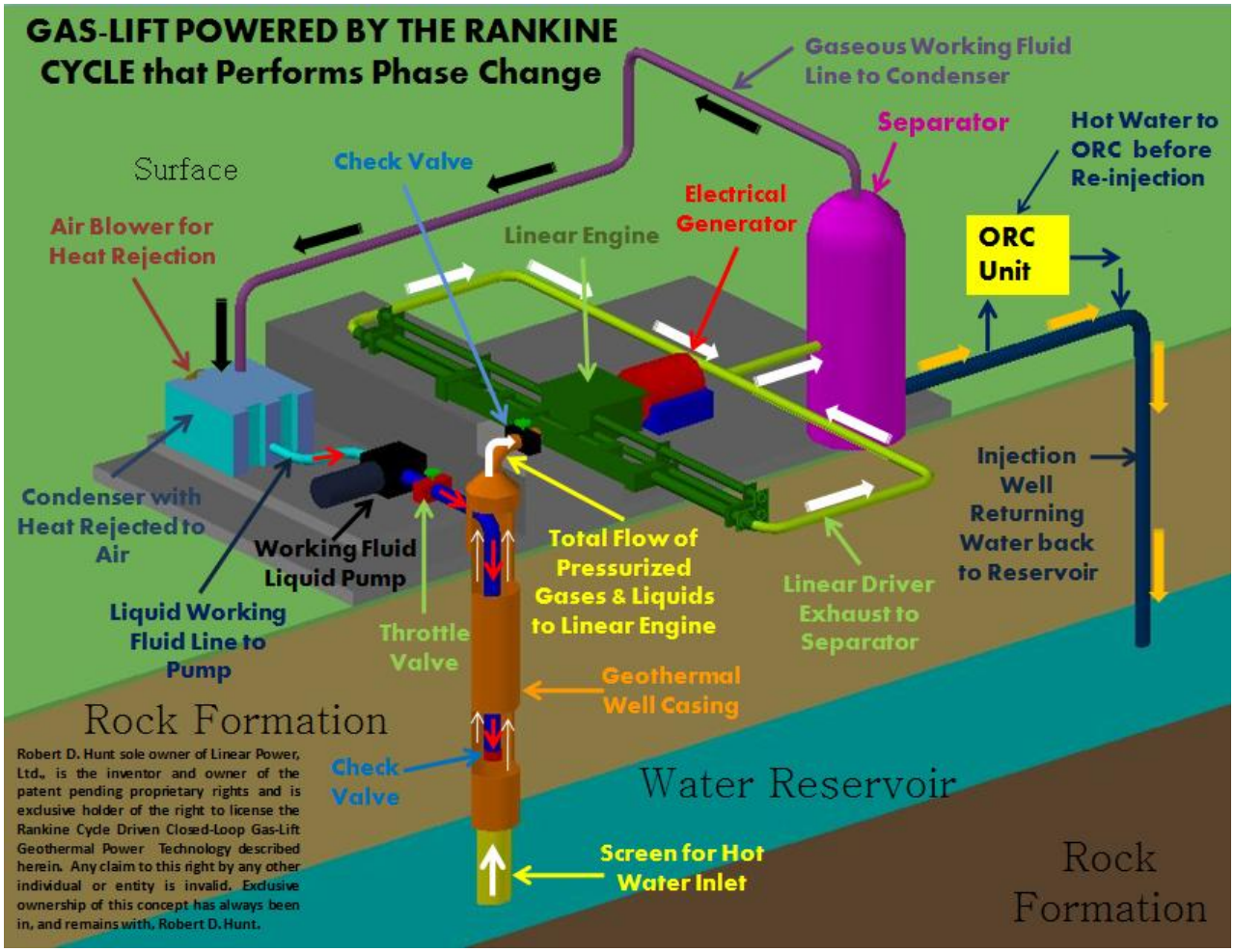

Figure 1. Presents a Schematic of the Rankine Cycle Powered Closed Gas-Lift Process that Powers a Kinetic Linear Engine

The scientific paper titled, "Evaluation of the Effect of Gravity on the Total-Flow Geothermal Power Cycle" presented by Robert D. Hunt during the Geothermal Resources Council (GRC) 2010 Annual Meeting held in Sacramento, CA on October 24, 2010 explains how the effect of gravity can potentially double the power output of geothermal power generation and solar thermal power using this closed proprietary Rankine cycle powered gas-lift process that gains additional power from gravity by making the water column lighter during the gas-lift process.

The benefits of total flow process were first evaluated and documented within the technical paper titled “The Total Flow Concept for the Recovery of Energy from Geothermal Hot, Brine Deposits” by A. L. Austin. The total flow power cycle may be summarized as a process by which the total flow of two-phase mixtures of liquids and gases are accelerated through a nozzle to high velocity having enhanced kinetic energy levels due to the drive force of the expanding gas that accelerates the high mass water to high velocities.

The water column of the well described in the paper while at equilibrium remained below surface level and water did not free flow to the surface. A water pump was placed on the well and it was then pumped creating suction, which resulted in lowering the pressure within the well that allowed a portion of the liquid water to boil into a low-density gas (steam produced by water flashing to vapor in response to lower pressure). The steam displaced high density water causing the overall water column to be less dense (lighter in weight) that resulted in a wellhead pressurized free-flow of water having over 300 psi pressure and the pump was no longer necessary. While at equilibrium the water's hydrostatic pressure and the reservoir pressure were the same. The hydrostatic pressure changed but the reservoir pressure remained the same resulting in the gas-lifted total flow of pressurized water and gases from the well being capable of producing power via harnessing their kinetic energy potential.

The Total Flow Concept paper that concluded that the amount of power output is approximately doubled by the gas-lift process provides clear mathematical evidence that there is greater power potential within geothermal wells and within oil and gas wells that may be converted to long-life geothermal power plants than is currently being produced by the use of ORC technology alone, using the kinetic energy potential of accelerated high mass liquids as part of the total flow of pressurized gases and liquids discharged from the well. This process also carries with it the additional benefit of providing the service of pumping water from the well, while producing greater net power generation instead of using power to drive a water pump as a parasitic power loss as is currently the case in conventional geothermal power cycles used today; thereby, providing additional net power output by two separate means -- the generation of kinetic power output and the elimination of pumping costs.

Prototype geothermal units are currently undergoing final engineering, which will then be fabricated and installed on operating natural gas wells with low-temperature water with an approximate temperature of 220 deg. F. having moderate geopressure just East of Houston,

Texas during late Summer of 2011. Additional kinetic energy will be generated and the hot brine water will be gas-lift pumped from the wells using a combination of the thermal energy contained in the water and by the effect of gravity on the gas-lift process that reduces the weight of the water column that allows the reservoir's geopressure to force the water from the well with even greater force. The accelerated total flow of high pressure gases and high mass water will drive a free-piston kinetic engine that uses a Sprague gear transmission to convert linear motion into rotation in a single direction in order to generate 250 kW of kinetic energy.

The resultant produced water that is partially cooled by the gas-lift process being in the 180 deg. F. range will power a thermal engine in order to generate an additional 150 kW of power from an estimated flow rate of 200 gallons per minute of brine solution before the water is re-injected into the reservoir after any natural gas is separated from the water. The water from the wells contains levels of natural gas being at or near saturation levels.

The Effect of Gravity on the Total Flow Gas-Lift Process that Pumps a Large Volume of Water and Generates Substantial Additional Power

The effect of gravity upon the total flow gas-lift geothermal process presented herein is modeled as a comparison of the results of a conventional organic Rankine cycle (ORC) power cycle as compared to the total flow gas-lift geothermal process performed within a well bore at substantial depth within the earth. The total flow gas-lift model describes the added effect of gravity (totally aside from the thermodynamic calculations in the model) on the energy output in order to model the fluid dynamics of the gas-lift process in order to provide additional understanding of the concept.

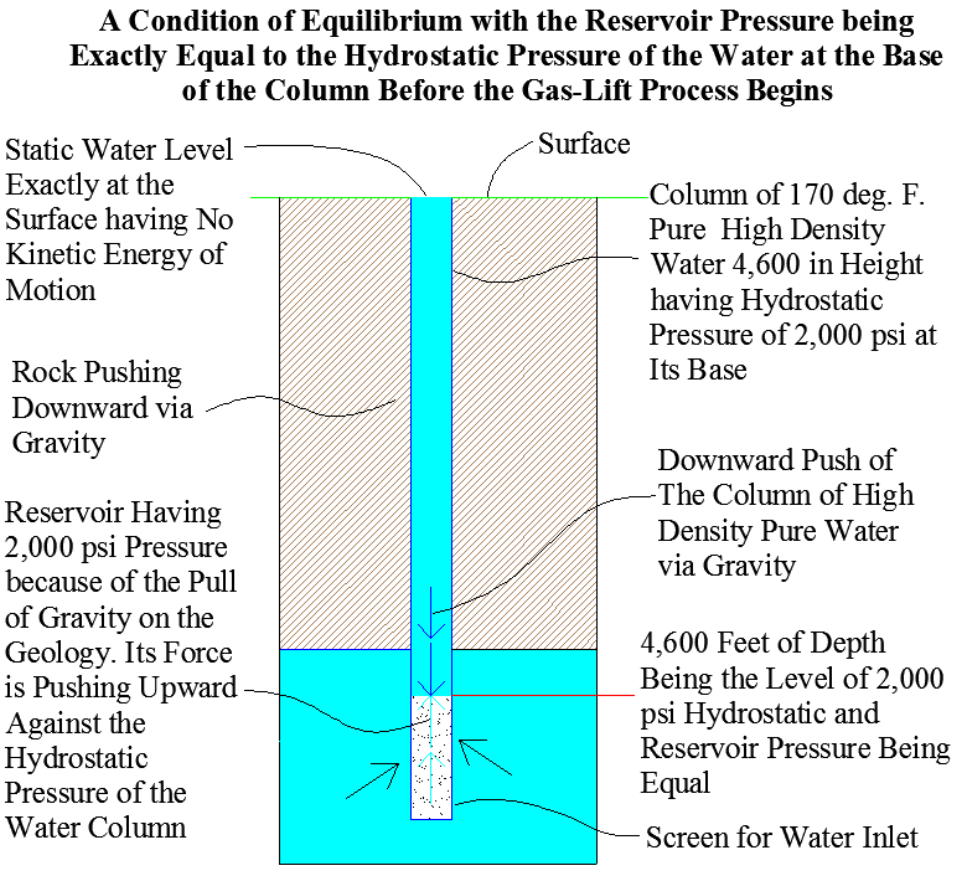

Figure 2. Describes a Geothermal Well at Equilibrium with the Reservoir Pressure Being Exactly Equal to the Hydrostatic Pressure of a Column of Pure Water Being 4,600 in Height

The model represented in Figure 2 features a column of pure water that is 4,600 feet in height having hydrostatic pressure in balance with the pressure of the reservoir -- not over pressured or under pressured, being in equilibrium such that the water rises to the surface exactly and does not flow out from the well or fall below the surface. These conditions require the water column's hydrostatic pressure and the pressure of the reservoir to be at equilibrium with the downward force of the water's hydrostatic pressure being exactly equal to the upward pressure of the reservoir being a force of nature caused by the gravitation attraction of the rocks, sand and other geology located above the 4,600 feet

The hydrostatic pressure of the 4,600 feet high water column at its base is 2,000 psi (calculated as the weight of a cubic foot of pure water being 62 lbs divided by its base being 12" X 12" that equals 144 square inches divide into 62 pounds that provides the result of .4333 psi per foot of depth, being solely derived from the weight of the water as a result of the gravitational pull of the earth. Therefore pressure of one pound per square inch is equal to and is capable of displacing water's hydrostatic pressure at 2.3 feet of depth (1 / .433 = 2.3). By extrapolation, 2,000 psi is equal to the hydrostatic pressure of pure water at a depth of 4,600; and, we know that the earth's

opposing pressure is also 2,000 psi in order for the column to rise exactly to the surface with the two forces being at equilibrium.

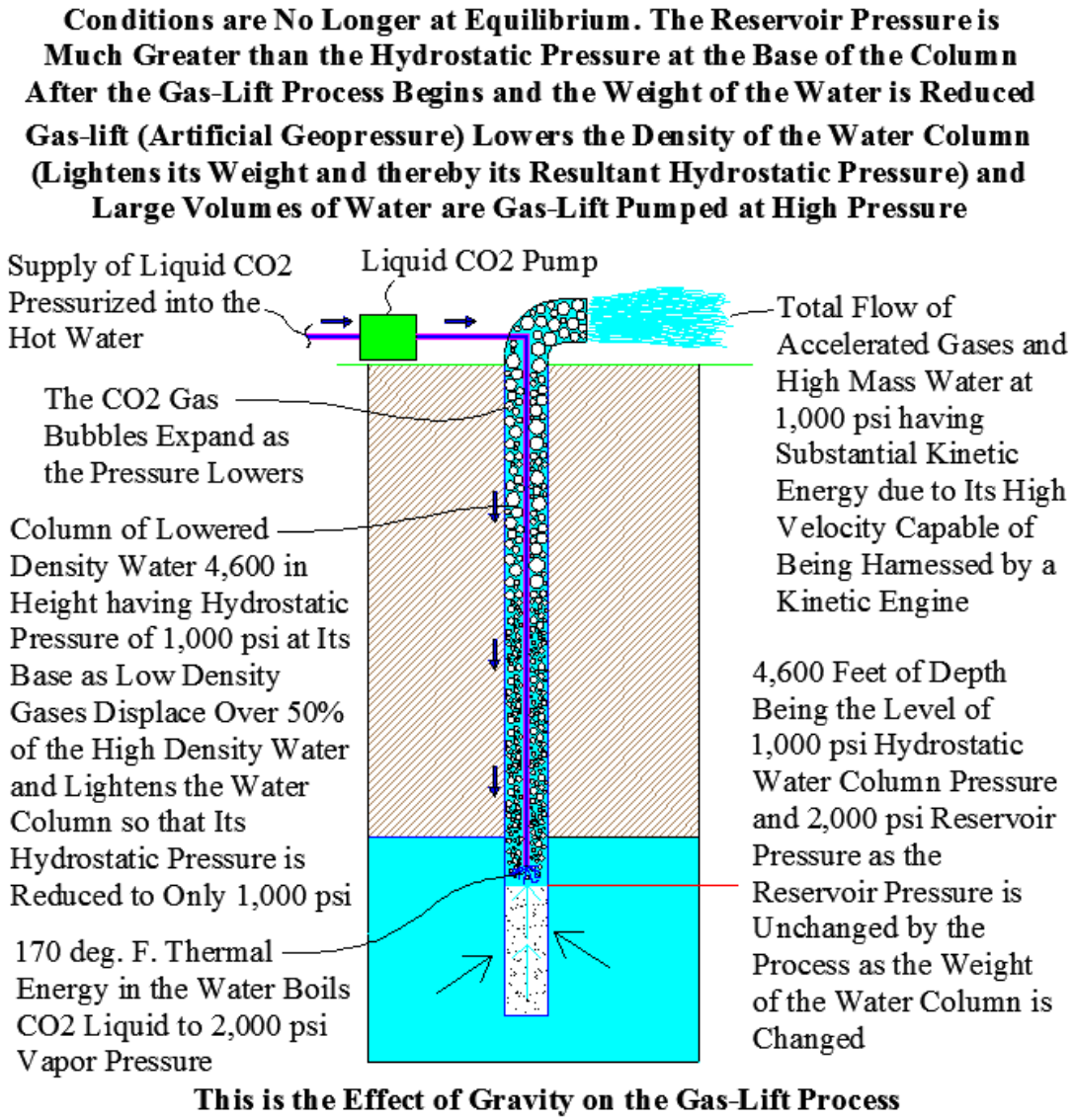

Figure 3. Describes the Changes of State as the Gas-Lift Process Begins and after the State of Equilibrium is Disturbed that Causes a High Pressure Total Flow of Water and Gases to be Pressurized from the Well Bore at High Velocity having Substantial Kinetic Energy

After the gas-lift process begins, the weight of the water column is altered as low density gas displaces high density water making it lighter. Thus, the status of equilibrium is disturbed. If by contrast an additive is placed in the water to make it heavier, the water column's height will fall below surface. Basically this is what drillers do with heavy drilling mud in order to stop over-pressured water flow from a well. But if the column is made lighter, then flow will be initiated.

The model assumes that the hot water temperature of 170 deg. F. is such that the liquid phase CO2 is vaporized into a high vapor pressure gas having pressure greater that the bottom hole pressure of 2,000 psi being capable of displacing high mass water with low density vapor. Due to the high pressure at the base of the well, the gas bubbles will be relatively small but as they rise and the pressure drops they will significantly increase in volume. Even though the initial bubbles are small in size, enough volume of working fluid is pumped to the bottom of the well that a significant amount of water volume is displaced.

The bubbles continue to grow as they rise to lower pressure and by the time the mixture of gases and water reach the surface, the gas is modeled to occupy one half of the total volume of the water column. One-half the total volume of water in the water column is displaced by vapor – less per cubic foot near the bottom with an ever increasing portion of gas per cubic foot of volume closer to the surface. If for simplicity you assume that the density of the lightweight gas is negated, the water column is only one-half as heavy as it originally was when it was all liquid.

The result of the effect of gravity is that the hydrostatic pressure at the base of the water column is only 1,000 psi. However since the push from the earth is unchanged it remains 2,000 psi. The net result is that a pumping action having a force of 1,000 psi is produced at the inlet to the well by the pressure of the reservoir, being the differential of forces after the water column's weight after being reduced by 50%. If the thermodynamic conditions were not such that the liquid working fluid could vaporize into a gas at that depth, this result could not be accomplished, but the conditions are such that it can vaporize. And as a result of the vaporization, the weight of the water column is altered and a significant and powerful gas-lift pumping force of 1,000 psi is created due to the effect of altering the density of the mass of the water column thereby lowing it gravitation pull.

The thermodynamic effect of vaporizing the liquid phase working fluid to a gas results in occurrence of the gas-lift pumping action by resulting in lowering the density of the water column by fifty percent (50%), but does not directly power the gas-lift pumping process, which is actually powered by the natural force of gravity as the "effect of gravity on the gas-lift process. Because the temperature of the water is only slightly changed by the vaporization gas-lift process, it only takes away a small amount of the thermal power generation potential via the use of a conventional surface ORC geothermal power unit. The pumping force is powered by the gravitational effect solely and is separate and apart from the thermodynamic effect and it stands on its own.

The gravitational effect and the thermodynamic process each stand on its own. This gravitational effect is a separate side effect of the thermodynamic process and totally independent from the thermodynamic process. It just occurs because the process that takes place changes the density of the water column and the gravitational effect itself is the result of the change in the gravitational

pull of the column of water that is thereby reduced due to its decrease in density as the opposing push from the pressure of the earth's reservoir is unchanged by the process.

Any high vapor pressure working fluid will perform adequately and most of the best working fluids are already produced by oil and gas wells. Working fluids with higher vapor pressure produce more power because they have greater capability to overcome the hydrostatic pressure of the water at greater depth and thereby more gas-lift pumping of the well is created. Carbon dioxide gas has the highest vapor pressure of all of vapors, Ethane is next and Propane is also adequate. All of these fluids are readily liquefied at the surface which is necessary to perform the Organic Rankine cycle. Then in a closed loop, the liquid phase working fluid is pumped back deep into the well-bore. The total flow concept that can gas-lift a pressurized flow of water and gases from geothermal wells or oil and gas wells that do not have geopressure opens the potential for a much larger number of wells to produce power via their kinetic energy.

Water Flow (gal/min)	CO_2 Flow (gal/min)	Well Depth (feet)	a. Pressure Power (kW)	b. Thermal Power (kW)	c. Total Power (kW)
1500	150	10000	1148	1364	2513
1500	300	10000	2239	1120	3359
1200	120	10000	926	1082	2013
1200	240	10000	1780	890	2690
1000	100	12000	809	1591	2400
1000	200	12000	1560	1396	2957

Table 1. Selection of Calculations Produced by Dr. Stathis Michaelides, Ph.D., P.E., Professor and Chair, Mechanical Engineering University of Texas at San Antonio, Texas

The above table represents the results produced by a calculator prepared by Dr. Michaelides. In Table 1 he refers to the results of the "effect of gravity" on the gas-lift process as "Pressure Power" cited in Column a.; ORC output is in Column b.; and Column c. is the total of the other two outputs combined. The output of the calculator is the maximum power (in kilowatts) that may be produced from the well flow by an ideal thermal or pressure engine. The maximum power that may be produced is given as: (a) power from the pressure of the fluid alone; (b) power from the temperature difference; and (c) total maximum power, which is the sum of (a) and (b). Each set of data is illustrative of the maximum potential of geothermal wells with injected fluids to produce power.

A lot of understanding can be gained from the Table. Note that the gas-lift kinetic energy power goes up almost linearly with the flow rate of the CO2 injected into the water; and, all of the figure totals are all over two megawatts of power; and, in the best cases being lines 2 and 4 from the top down both produce sixty-seven percent (67%) of their power from the kinetic energy of pressure power.

Comparison in Regard to the Production of Kinetic Energy of a Conventional Organic Rankine Cycle (ORC) Performed on the Surface Using Indirect Heat Exchange to The Total Flow Gas-Lift Process Performed by Direct Heat Exchange at Depth Within a Well Bore

The analysis shown in Figure 4 regarding the energy required to pump the working fluid to depth into the well shows that the input power does not change to a substantial degree from that of a conventional Rankine cycle performed on the surface, which it typically from ten percent (10%) to fifteen percent (15%) of the gross power output generated. The liquid phase working fluid must be pumped into the pressurized boiler in a conventional ORC. In the model the boiler is at the same temperature as the bottom of the well of 170 deg. F. Therefore, the vapor pressure within the boiler is also 2,000 psi, being equivalent to the hydrostatic pressure at the bottom of the well.

Figure 4 describes a conventional organic Rankine Cycle (ORC) unit comprising a liquid pump that pressurizes liquid phase working fluid into a vaporizer (boiler) in order to vaporize the liquid into high vapor pressure gas using thermal energy contained in the heat source being 170 deg. F. water pumped from the geothermal well in order for the energy contained in the gas to drive a prime mover, such as an expansion turbine, twin screw expander or positive displacement free-piston engine. The expanded and cooled vapor discharged from the prime mover is cooled and condensed by a cool source in order to provide a continuous supply of liquid working fluid to the liquid pump and to complete the ORC cycle.

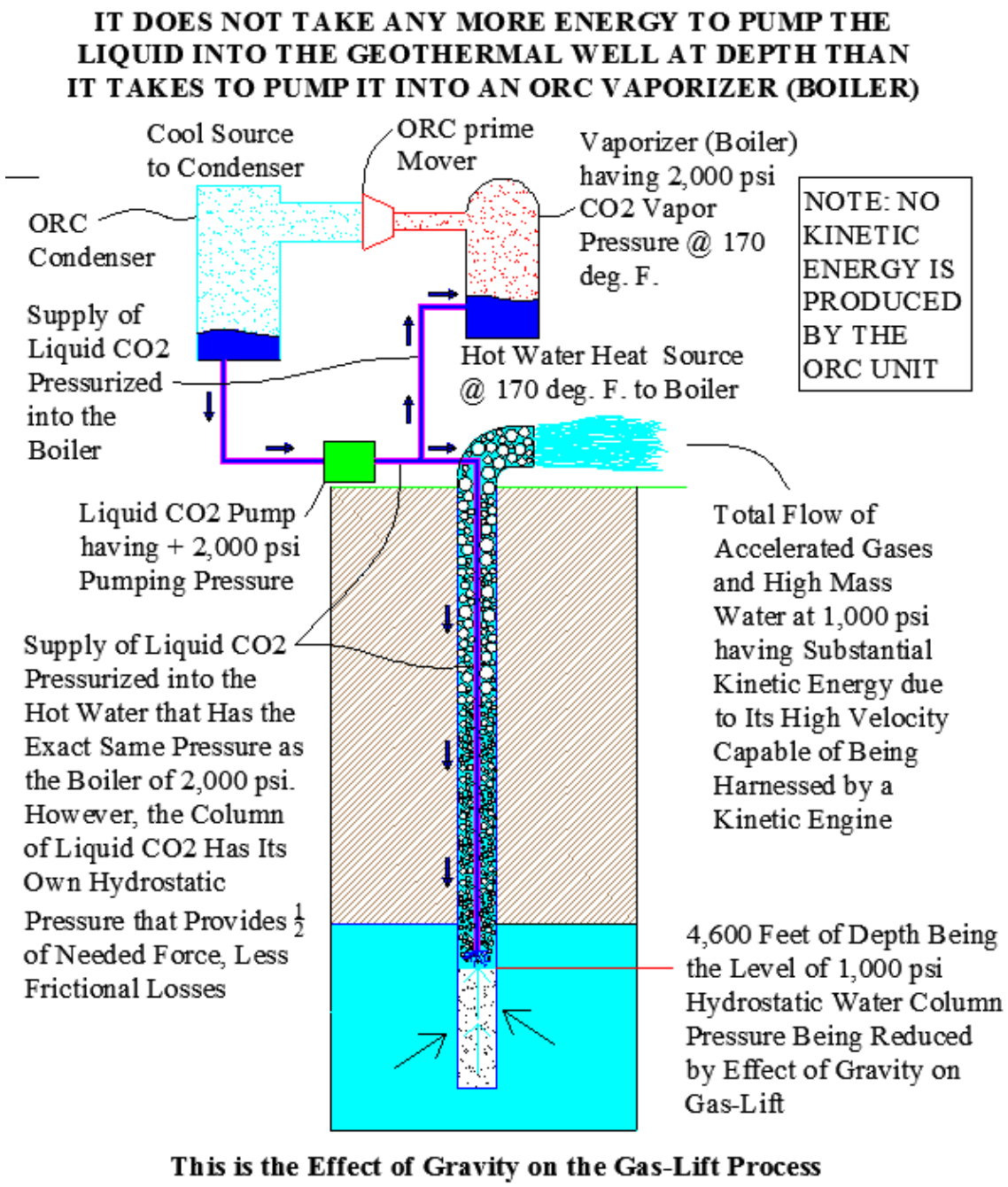

Figure 4. Provides an Analysis of the Power Input Required to Pressurize the Liquid Phase Working Fluid into an ORC Boiler at 2,000 psi as Compared to the Power Input to Pressurized the Liquid Phase Working Fluid into Casing of the Geothermal Well at 4,600 feet of Depth Also Being at 2,000 psi

The ORC is compared to the total flow gas-lift process described herein that is also powered by a Rankine cycle modified to drive the gas-lift process in order to beneficially gas-lift pump large volumes of water and to attain additional power as the result of "the effect of gravity on the gas-lift process" that creates "kinetic energy" in the form of "pressure power' – being the high

pressure total flow of gases and liquids at high velocity forced from the well by the pressure of the reservoir being greater than the opposing weight (hydrostatic pressure) of the water column after the gas-lift process begins. The kinetic energy generated by the gas-lift process may be harnessed using the free-piston engine described herein that specifically designed for the purpose.

Natural Gas Saturated into Brine Produced from Oil and Gas Wells

Separated natural gas recovered may be used to generate additional power. House, P. A., Johnson, P. M, and Towse, D. F., 1975 within their paper titled "Potential Power Generation and Production from Gulf Coast Geopressure Reservoirs" were among the first authors to report the large amount of gas entrained within brine water at elevated temperatures and pressures at reservoir depths from 5,000 to 20,000 feet of depth with corresponding temperatures from below 200 deg. F. to above 300 deg. F. with natural gas presumed to exist at saturation levels in these reservoirs. Total-flow, flashed-steam, and binary-cycle thermal energy conversion systems were investigated as a means to utilize the thermal energy.

Further studies have determined that the saturation of natural gas within pressurized brine solutions in sedimentary Permian basins is generally greater than 20 cubic feet per barrel and being normally less than 60 cubic feet per barrel of water produced. For a geothermal application of these wells producing large volumes of water in order to extract thermal energy, the amount of gas that can be extracted to generate additional power is very substantial. The fact that a new Federal Law provides that oil and gas produced in association with geothermal power generation is exempt from payment of the oil and gas severance tax provides an additional economic advantage to performing oil and gas / geothermal co-production.

RenewableOne Project in Santa Rosa County, Florida

In 2010 RenewableOne studied both the geothermal resource potential and the business case as it relates to Oil and Gas / Geothermal Co-Production in Santa Rosa County, Florida (Panhandle Region) located just east of Pensacola. The fields in the area are an extension of the Jay Field.

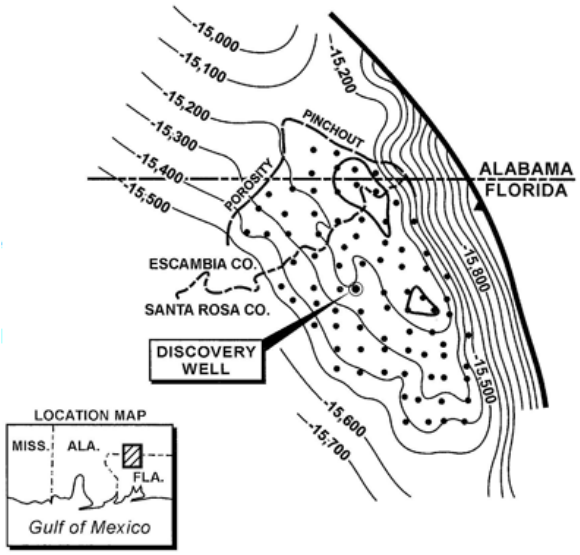

Figure 5. Structure Map -- Top of the Smackover, Jay Field Located in Southern Alabama and the Western Florida Panhandle after Ottomann, Keves, and Ziegler, Transaction -- Gulf Coast Association of Geological Societies, Vol. XXIII, 1973.

Of particular focus were the existing well bores located along U.S. 90/I-10 in a geographic grouping within a 10-mile radius. These 14 existing oil-and-gas well bore assets present ripe geothermal resources ranging in depth of 14,000-17,000 feet with bottom hole temperatures of 225-278 degrees Fahrenheit.

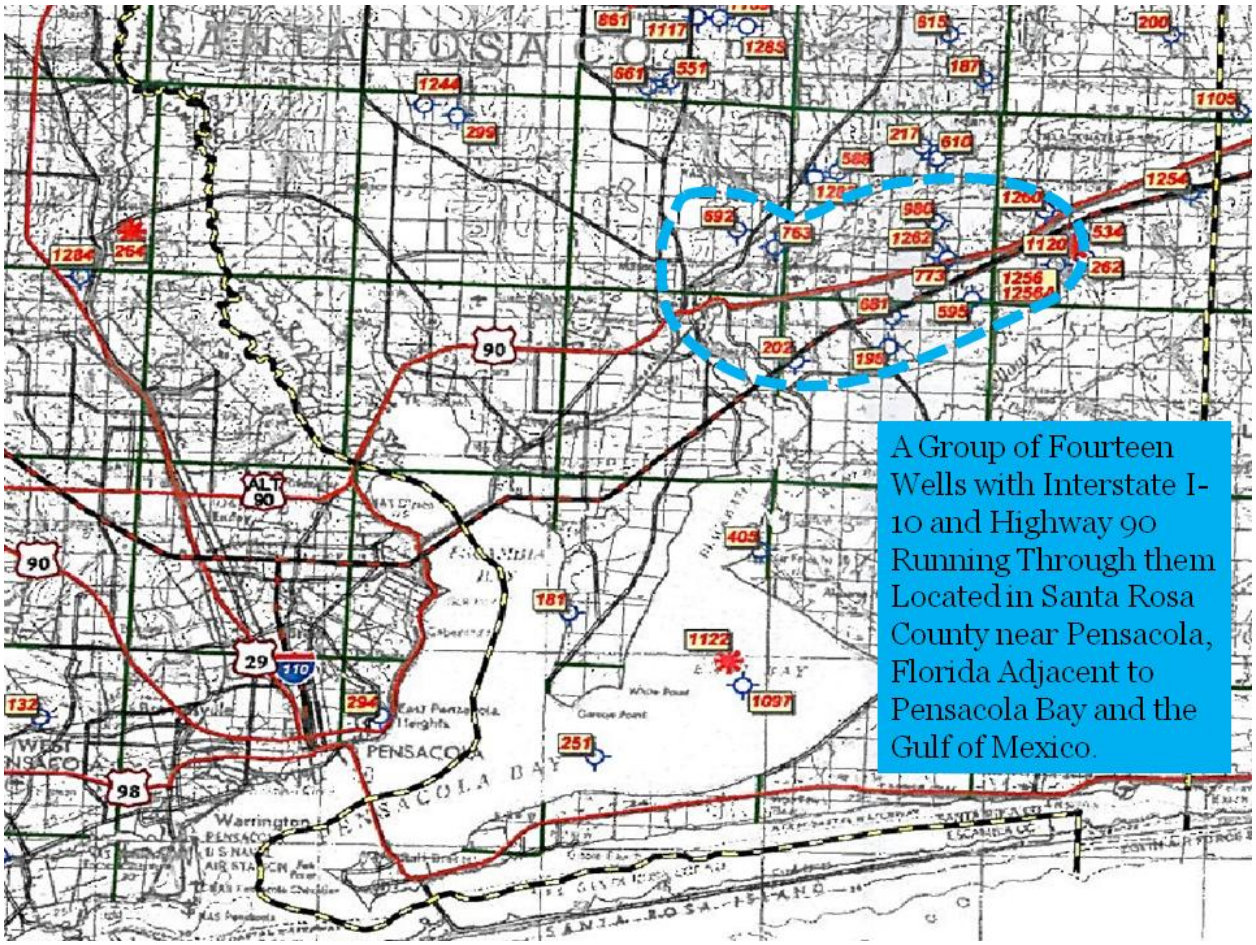

Figure 6. A Group of 14 Wells being Considered for Oil and Gas / Geothermal Co-Production by RenewableOne a Company Specializing in the Integration of Real Estate Development Associated with Renewable Energy Power Generation; Map Source – State of Florida Oil and Gas Program

This area of Florida is deemed especially viable for oil and gas / geothermal co-production development because this region is largely developed as a commercial and industrial corridor along Highway 90 having large industrial parks that can utilize the generated electrical power and can use space heating and cooling provided by the process for the associated building structures. Co-generation of useful heat that can also be used to produce cooling via absorption chiller means and other technologies dramatically improves the economics of the proposed project.

Engineering performed by RenewableOne projects that by utilization of the Hunt technology described herein that an estimated power output of two megawatts per well for a total of 28 megawatts of name plate capacity for the 14 well field that are presently shut-in or otherwise idle. While Florida and the local utility market do not feature Feed-In Tariffs and RPS legislation favorable for renewable power generation, RenewableOne reported that they still found much

cooperation and a strong business case in working together with the State of Florida (public approvals) and Gulf Power Company, the Southern Company subsidiary that is the owner of local power distribution rights.

RenewableOne expects to gain additional benefits from use of the technology for its planned clean energy park project adjacent to the wells through useful heating, cooling, and the generation of renewable energy to power the manufacturing of other renewable energy devices in an environmentally responsible and sustainable manner.

Southern Florida Peninsula Oil and Gas De-Watering Application

Additionally, the author was approached by an oil and gas operator located on the Southern Peninsula of Florida regarding de-watering applications. The company reported that most of their income is expended in order to pay for diesel in order to provide water pumping at costs substantially higher than those that would have been charged by their local utility if service was available to the stranded production wells. It was concluded that onsite pumping to withdraw water from the production wells and pumping to re-inject the water after removal of hydrocarbons back into the reservoir can be met by the technology described herein. The Rankine power cycle driven gas-lift process can be used to gas-lift pump water from the wells with the power generated by the kinetic energy of the total flow of liquids and gases being capable of providing electrical power for all other electrical needs. The produced water can be pressurized back into the reservoir using a thermal hydraulic pump, being a thermal engine connected to a positive displace piston water pump. The thermal engine uses water having a lower temperature and lower pressure that is discharged from the kinetic engine whereby heat exchange is provided by indirect heat exchange to the working fluid of thermal engine.

Summary

This study has concluded that there is a very substantial potential to produce geothermal power in association with oil and gas within the State of Florida; and, oil and gas / geothermal co-production was determined to be the most cost effective and most practical means of generating geothermal renewable energy within the State. The study further determined that substantial additional benefits can be derived from the process in regard to space heating and cooling for building structures adjacent to the wells and that the power generated can be used to power factories adjacent to the wells that produce valuable commercial and industrial products. These two cases of use of oil and gas / geothermal co-production in Florida presented are certainly not the only viable uses in Florida and are used herein to illustrate the potential of the technology; and, the result is positive that this new method of geothermal power generation as applied to old oil and gas wells holds great promise for use within the State of Florida.

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Stathis Michaelides, Ph.D., P.E., Professor and Chair, Mechanical Engineering University of Texas at San Antonio, Texas written report concerning verification of the accuracy of mathematics and the preparation of an interactive spreadsheet Calculator that models the effects of gravity on the Total Flow Concept Geothermal Power Cycle Technical Paper described herein.

Information regarding oil and gas wells within the State of Florida used within this paper was attained from the Oil and Gas Program that is the permitting authority within the Department's Mining and Minerals Regulation Program.
http://www.dep.state.fl.us/water/mines/oil_gas/index.htm.

Acknowledgements

The author wishes to thank Craig Laher, CEO of RenewableOne, for his contributions to this paper in providing data regarding the Santa Rosa County RenewableOne project under development. www.renewableone.com

The author wishes to thank the Houston Advanced Research Center (HARC), especially Dr. Jim Lester - Principal Investigator, Dr. Robert Harriss - HARC President, and Dr. Bill Merrell - Acting President A&M Galveston and HARC Board Member, for their dedication to this project. HARC is a non-profit research center created by Dr. George Mitchell and his family that is supported by A&M University that serves as a boundary organization bridging the gaps between basic research in renewable energy and commercial application. HARC manages the Solar America Cities Program for the City of Houston, TX. and administers the Environmental Drilling Program for REPSEA. There is no financial relationship between HARC and Mr. Hunt or his related companies. HARC’s role is to serve as a neutral evaluator of Mr. Hunt's technologies. http://www.harc.edu/