NEW BINARY GEOTHERMAL POWER SYSTEM

Alexander I. Kalina[1]

[1]Kalex, LLC., 2630 Carlmont Drive, Belmont California, 94002 USA.
alexander_kalina@yahoo.com

KEY WORDS

Geothermal, Kalina Cycle.

ABSTRACT

A new type of power system utilizing a variable composition, multi-component working fluid power cycle (conventionally referred to as a Kalina cycle) has been developed by Kalex LLC. This system is designed mainly for utilizing heat from liquid dominated geothermal sources. The composition of the system's working fluid changes in different parts of the system, which allows the system to achieve high thermodynamical (exegetical) efficiencies (*the thermodynamical efficiency is the ratio of the actual thermal efficiency of the system to the maximum theoretical efficiency according to the Second Law of Thermodynamics*). The composition of the working fluid is also variable based on the ambient temperature, which allows for the maintenance if a high thermodynamical efficiency with changing weather conditions. Although a water-ammonia mixture is the intended mixture for the system's working fluid, the system can also work with a mixture of freons and/or hydrocarbons. This system works in an optimum manner with an initial temperature of geofluid from 380°F to 250°F (180°C to 120°C). The thermodynamical efficiency of the system is always within the range from 50% to 60%. Thus, at any boundary conditions within the operational range, the efficiency is from 20% to 40% higher than the efficiency of systems based on the organic Rankine cycles which are conventionally used for the utilization of these types of geothermal sources.

1. INTRODUCTION

Initially, utilization of geothermal energy sources was focused upon the utilization of steam dominated resources. In such cases, geothermal steam was expended in the turbine to produce power. In this manner, the working fluid of the power cycle was the geofluid itself. Thereafter, when the great majority of steam dominated had already been utilized, there was a growing interest in the utilization of liquid-dominated resources. Such utilization required the use of closed thermodynamical cycles with a working fluid which was different from the geofluid. Such systems are conventionally referred to as "binary systems". The initial interest in liquid dominated resources focused on relatively high temperature resources, but as these high temperature resources had, for the most part, been utilized, the focus has shifted to lower temperature resources.

Since, in accordance to the Second Law of Thermodynamics, the lower the temperature of heat source, the lower the efficiency of the power system utilizing this source. Because of this fact, in order to produce a given unit of power output, it is necessary to process a greater and greater amount of heat, which it its turn leads to an increase of the capital cost of the installation. From these facts, it becomes obvious that the use of systems with the highest possible thermodynamical efficiency is paramount to the development of geothermal energy.

2. GEOTHERMAL POWER SYSTEMS UTILIZING KALINA CYCLES

2.1 Definitions

Scientifically, the Kalina cycle is defined as a power cycle utilizing a mixture of at least two components as a working fluid, in which the composition of the working fluid varies in different parts of the system.

This definition is distinct from the trademarks "Kalina Cycle" and Kalina Cycle Technology" which are registered trademarks of Exergy, Inc., a California corporation. It is important to note that though this corporation owns the patents to some early examples of Kalina cycles, its trademark and patent rights do not cover all Kalina cycles.

Accordingly, when this paper refers to "Kalina Cycle Technology" as covered by the trademarks noted above, these references shall appear in quotations. Whereas, where this document shall refer to the generally accepted and applicable scientific definition of the Kalina cycle, is shall appear without quotation.

The latest generation of systems that fall within the scientific definition Kalina cycle are hereafter referred to by the trademarked term "Kalex Technologies". These latest systems and the trademark "Kalex Technologies" are **not** owned by or licensed to Exergy, Inc. Rather they are owned by Kalex LLC, a corporation of California.

2.2 First Generation Kalina Cycle System for Geothermal Application

The initial "Kalina Cycle" system for geothermal applications was developed more than 12 years ago. This system was designated "KCS-11" or "Kalina Cycle System 11". It was designed to utilize geothermal resources with initial temperatures 375°F or higher.

A flow diagram of KCS-11 is presented in Figure 1. KCS-11 works as follows: Fully condensed working fluid with parameters as at point 1 is pumped by feed pump P1 to a required high pressure and obtains parameters as at point 2. Then the stream with parameters as at point 2 passes through a preheater HE2 where is heated in counterflow by a returning stream of working fluid 26-27 (see below) and obtains parameters as at point 3, corresponding to a state of saturated liquid. Then the stream with parameters as at point 3 is divided into two substreams, with parameters as at points 4 and 5 correspondingly. The substream with parameters as at point 4 passes through a boiler HE5 where it is heated in counterflow by a stream of geofluid 42-43 (see below) and partially vaporized, obtaining parameters as at point 6. The substream with parameters as at point 5 passes through a recuperative boiler-condenser HE3 where it is heated and partially vaporized by a returning stream of working fluid 18-26 (see below), and obtains parameters as at point 7. The parameters of the working fluid at points 6 and 7 are either the same or very similar. Thereafter substreams 6 and 7 are combined forming a stream with parameters as at point 8. The stream with parameters as at point 8 passes through heat exchanger HE6 where it is fully vaporized and superheated, obtains parameters as at point 17and enters into the turbine T1. In turbine T1 the working fluid is expanded, producing power, and obtains parameters as at point 18. At point 18 the working fluid is usually slightly wet. The stream with parameters as at point 18 passes through the boiler-condenser HE3 where it is partially condensed, releasing heat for process 5-7 (see above), and obtains parameters as at point 26. The stream with parameters as at point 26 passes through preheater HE2 where it is further cooled and condensed, providing heat for process 2-3 (see above), and obtains parameters as at point 27. Thereafter the stream with parameters as at point 27 enters into a condenser HE1 where it is fully condensed by air or water, obtaining parameters as at point 1. The cycle is closed.

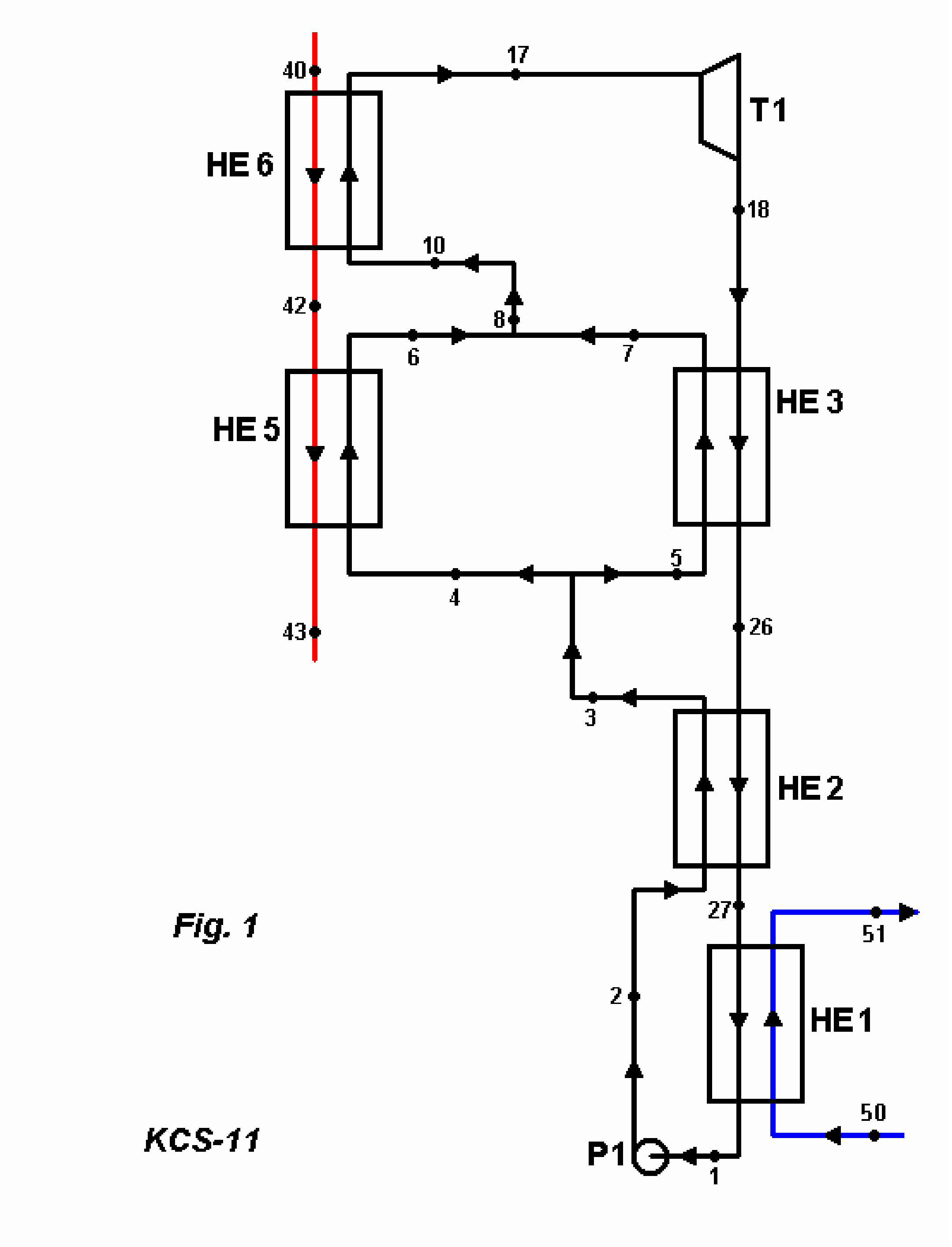

Fig.1 KCS-11

Geofluid with initial parameters as at point 41 passes through heat exchanger HE6 where it is cooled, providing heat for process 8-17 (see above) and obtains parameters as at point 42. Then the stream of geofluid with parameters as at point 42 passes through boiler HE5 where it is further cooled, providing heat for process 4-6 (see above) and obtains parameters as at point 43.

To attain a desired high efficiency of a this system, it is necessary that the temperature differences in between points 42 and 6 and in between point 18 and 7 be kept to a minimum. To achieve this, it is necessary to properly choose the composition of the working fluid in such a way that the sum total of heats from processes 42-43 and 18-26 are equal to the required heat of process 3-8 while still maintain the needed minimum temperature differences. Such a composition of working fluid is referred to as a "balancing composition". If the composition of the working fluid is richer (i.e. has a higher concentration of the light-boiling component) than the balancing composition, the quantity of heat released in process 18-26 is reduced and the temperature difference in between point 42 and 6 must be increased which results in a lowering of the thermodynamical efficiency of the process.

As is seen from the description of the system above, the composition of the working fluid remains non-variable through the whole system. Therefore according to a strict scientific definition, the power cycle of "Kalina Cycle" system KCS-11 is not in fact a Kalina cycle, since the composition of the working fluid is not varied.

When the cooling air temperature changes (for instance, due to weather), the balancing composition must be changed accordingly. Therefore, for the efficient operation of system KCS-11 it is necessary to have an auxiliary subsystem to provide the required change in the working composition.

If the initial temperature of the geofluid is lowered, the balancing composition cannot be fully vaporized and the working composition must thus be richer than the balancing composition, thus lowering the thermodynamical efficiency of the system. If the temperature of the cooling medium is lowered, the pressure of condensation, and therefore the back pressure of the turbine is likewise lowered. This reduces the quantity of heat released in process 18-26 and therefore causes the required balancing composition to become leaner, but in such a case, this leaner balancing composition may not be able to be vaporized at the given initial temperature of the geofluid.

Currently, there are very few available geothermal sources with initial temperatures of 375° F or thereabouts. The vast majority of such sources that do exist are already tapped. Currently in the geothermal industry, most available sources have initial temperatures of less than 320° F. As was demonstrated above, KCS-11 is not well suited for these sources. Its advantages over a conventional Rankine cycle are largely lost with these low temperate sources; the lower the temperature of the source, the greater the loss of any useful advantage of KCS-11.

Therefore it was necessary to develop a new type of geothermal system based upon the cycle with a variable composition of working fluid, i.e. a Kalina cycle. Kalex LLC has developed a new generation of power systems based on the Kalina cycle, including a new geothermal system that the problems described above.

2.3 Kalex power cycle and system for utilizing moderate and low temperature heat sources

This new geothermal system is designed for the utilization of heat sources with moderate to low initial temperature, such as geothermal, waste heat, and similar sources has been designated as Kalex SG-2. (System, Geothermal # 2)

The flow diagram of this system is shown in Figure 2.

The system operates as follows:

Fully condensed working fluid, at a temperature close to the ambient, with parameters as point 1, enters into a feed pump, P1, where it is pumped to an elevated pressure, and obtains parameters as point 2. We shall hereafter refer to the composition of this working fluid as a “basic composition”, or “basic solution”.. The stream of working fluid with parameters as point 2 passes through a recuperative pre-heater, (heat exchanger HE2), where it is heated in counter flow by a returning stream of the same working solution (see below), and obtains parameters as point 3. The state of the basic working solution at point 3 corresponds to the state of saturated, or slightly subcooled liquid .

Thereafter the stream of basic solution, having parameters as point 3 is divided into two substreams, having parameters as points 4 and 5 correspondingly. The stream with parameters as at point 4 passes through heat exchanger HE4, where it is heated and partially vaporized by a steam of heat source fluid (in the case of geothermal application, a stream of geothermal fluid.) (see below)., and obtains parameters as point 6. The stream of basic solution with parameters as at point 5 passes though heat exchanger HE3, where it is heated and partially vaporized by a condensing stream 20-21 (see below), and obtains parameters as point 7. Thereafter the substreams with parameters as points 6 and 7 are combined, forming a stream parameters as point 8. Thereafter the stream of basic solution with parameters as at point 8 passes through heat exchanger HE7, where it is heated and further vaporized in counterflow by a stream of geothermal fluid and obtains parameters as at point 14. This stream of basic solution with parameters as at point 14 is combined with a stream of recirculating solution having parameters as at point 29, (see below), forming a combined stream with parameters as at point 10. The stream with parameters as at point 29 is in a state of a subcooled liquid.

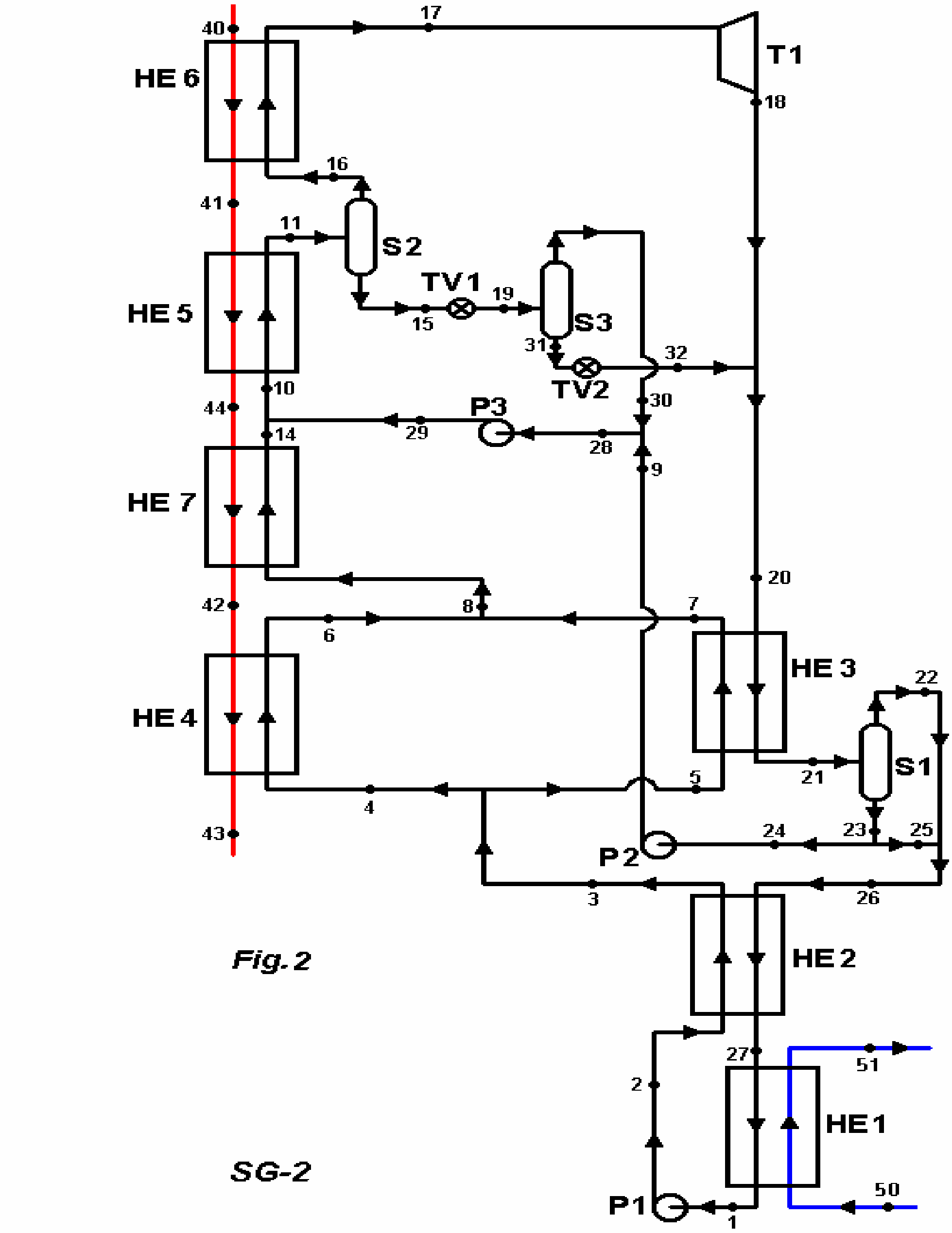

Fig.2 SC-2

In a general case if a stream of boiling vapor-liquid mixture is mixed with a stream of subcooled liquid, the resulting temperature is different from the initial temperature the boiling vapor-liquid mixture; the temperature can increase or decrease. But in the case of mixing streams with parameters as at points 14 and 29 correspondingly, the temperature of stream 14 is chosen in such a way that after mixing with stream 29, the temperature of the resulting stream 10 is equal or very close to the tempter at point 14. We will refer to a stream with a composition as at point 10 as a “boiling solution”.

A stream of boiling solution, having parameters as point 10 passes through heat exchanger HE5, where it is heated and vaporized by a stream of heat source fluid, and obtains parameters as point 11. The stream with parameters as point 11 then enters into a gravity separator, S2, where it is separated into a stream of vapor having parameters as point 16, which is referred to as a "working solution" and a stream of liquid having parameters as point 15. The stream of working solution with parameters as point 16 passes through heat exchanger HE6 (superheater) where it further heated by heat source fluid, where it is superheated, and obtains parameters as point 17. Thereafter the stream of working solution, having parameters as point 17 passes through a turbine, T1, where is expanded, producing useful power, and obtains parameters as at point 18.

Recirculating liquid with parameters as point 15 (see above) passes through a throttle valve TV1, where it’s pressure is reduced to an intermediate pressure , and obtains parameters as point 19. As a result of throttling, the parameters of the stream at point 19 correspond to a state of a vapor-liquid mixture. The stream with parameters as point 19 then enters into a gravity separator S3, where it is separated into a stream of vapor having parameters as point 30, and a stream of liquid having parameters as point 31. The stream of liquid with parameters as point 31 passes through a throttle valve, TV2, where it’s pressure is further reduced to a pressure equal to the pressure at point 18 (see above), and obtains parameters as point 32. Thereafter the stream with parameters as point 32 and the stream with parameters as point 18 are combined forming a stream of condensing solution with parameters as point 20. The stream with parameters as point 20 passes through a heat exchanger, HE 3, in counter flow to stream 5-7, where it is partially condensed, releasing heat for process 5-7 (see above) and obtains parameters as point 21.

The stream with parameters as point 21 then enters into a gravity separator S1, where it is separated into a stream of vapor with parameters as at point 22 and a stream of liquid with parameters as point 23. The stream of liquid with parameters is in its turn divided into two substreams with parameters as points 25 and 24 respectively. The stream of liquid of liquid with parameters as point 25 is then combined with the stream of vapor with parameters as at point 22, forming a stream of basic solution with parameters as point 26.

The stream of liquid with parameters as point 24 enters a circulating pump P2, where it’s pressure is increased to a pressure equal to the pressure in gravity separator S3, i.e., equal to the pressure of the stream of vapor with parameters as point 30 (see above), and obtains parameters as point 9. The stream of liquid with parameters as point 9 is in a state of a subcooled liquid. The stream of liquid with parameters as point 9 is then combined with a stream of vapor with parameters as point 30 (see above). The pressure of the streams with parameters as points 9 and 30 is chosen in such a way that the subcooled liquid with parameters as point 9 fully absorbs all of the stream of vapor with parameters as point 30, forming a stream of liquid with parameters as point 28. The liquid at point 28 is in a state of saturated or slightly subcooled liquid. Thereafter the stream with parameters as at point 28 enters into a circulating pump, P3, where its pressure is increased to a pressure equal to the pressure at point 14, and obtains parameters as point 29. The stream with parameters as point 29 is then combined with a stream of basic solution with parameters as point 14, forming a stream of boiling solution with parameters as point 10 (see above).

The stream of basic solution having parameters as point 26 enters into heat exchanger HE2, where it partially condenses releasing heat for process 2-3, (see above), and obtains parameters as point 27. Thereafter the stream of basic solution with parameters as point 27 enters into a condenser HE1, where its is cooled and fully condensed by a stream of air or water with parameters as at point 50 (see below), and obtains parameters as point 1.

The stream of air or water with parameters as point 50 enters HE1 where it cools the stream of basic working fluid in process 27-1, and obtains parameters as at point 51.

The stream of heat source fluid with parameters as point 40 passes through heat exchanger HE6, where it provides heat for process 16-17, and obtains parameters as point 41. The stream of heat source fluid with parameters as point 41 passes through heat exchanger HE5, where it provides heat for process 10-11, and obtains parameters as at point 44. The stream of heat source fluid with parameters as point 44 enters into heat exchanger HE7, where it provides heat for process 8-14 and obtains parameters as at point 42. The stream of heat source fluid with parameters as point 42 enters into heat exchanger HE4, where it is cooled, providing heat for process 4-6, obtains parameters 43 and is removed from the system.

In the system described above, the liquid produced in separator S1 eventually passes through heat exchanger HE5 and is partially vaporized. However, the composition of this liquid is only slightly richer than the composition of the liquid separated from the boiling solution in separator S2. In general, the richer the composition of the liquid added to the basic solution, as compared to the composition of the liquid added to the spent working solution (point 18), the more efficient the system. In the proposed system, the bulk of liquid from separator S2, having parameters as point 15 is throttled to an intermediate pressure, and then divided into vapor and liquid in separator S3. As a result, the liquid with parameters as point 32 which is mixed with the spent working solution, with parameters as point 18, is leaner than the liquid separated from the boiling solution in separator S2. In addition, the recirculating liquid which is separated in separator S1 is mixed with vapor from separator S3, and therefore is enriched. As a result, the liquid with parameters as point 29, which is added to the stream of basic solution with parameters as point 10, is richer than the liquid produced from separator S1.

The thermodynamical cycle performed by the system described above can be interpreted as being comprised of two interacting power cycles. The first cycle is performed by the basic solution, which passes through all the heat exchangers of the system, through the turbine, and through separator S1. Rejected heat from this cycle is removed in condenser HE1. The second cycle is performed by the recirculating solution (i.e. part of the liquid removed in gravity separator S1; stream 24). This passes through heat exchanger HE5 and enters into separator S2. Then the vaporized portion of this solution becomes part of stream 16, and passes through heat exchanger HE6 and through the turbine T1. Meanwhile, the liquid portion of the solution passes through separator S3 and then is combined with the turbine exhaust, passes through heat exchanger HE3 and enters separator S1, from which it is removed in the form of liquid. Heat rejected by this supplementary cycle is utilized in heat exchanger HE3, where it is used for process 5-7.

For an initial temperature of geofluid of 315°F. and a temperature of cooling air of (ambient) of 51°F, the parameters of the key points of the described system are given in table 1, and the summary of its performance is given in table 2.

Table 1.

Pt.	X lb/lb	T °F	P psia	H Btu/lb	S Btu/lb•°F	G rel G/G=1
1	0.9250	73.27	126.1295	20.7399	0.08336	1.00000
2	0.9250	74.66	498.6754	22.9337	0.08423	1.00000
3	0.9250	165.00	478.6754	130.1713	0.26958	1.00000
4	0.9250	165.00	478.6754	130.1713	0.26958	0.58070
5	0.9250	165.00	478.6754	130.1713	0.26958	0.41930
6	0.9250	208.95	476.6754	517.8877	0.88025	0.58070
7	0.9250	208.95	476.6754	517.8877	0.88025	0.41930
8	0.9250	208.95	476.6754	517.8877	0.88025	1.00000
9	0.3977	170.33	224.8710	46.5602	0.21789	0.29313
10	0.8065	250.57	475.6754	484.4892	0.83867	1.30952
11	0.8065	303.50	474.6754	649.7172	1.06276	1.30952
14	0.9250	250.57	475.6754	608.7261	1.01224	1.00000
15	0.3423	303.50	474.6754	205.2959	0.44091	0.17842
16	0.8797	303.50	474.6754	719.8217	1.16086	1.13110
17	0.8797	306.00	473.1754	721.7769	1.16374	1.13110
18	0.8797	212.09	132.1295	642.5485	1.18461	1.13110
19	0.3423	255.90	224.8710	205.2959	0.44605	0.17842
20	0.8055	213.95	132.1295	581.3523	1.08250	1.29313
21	0.8055	170.00	130.1295	455.6339	0.89121	1.29313
22	0.9755	170.00	130.1295	626.4526	1.17212	0.91259
23	0.3977	170.00	130.1295	45.9869	0.21753	0.38054
24	0.3977	170.00	130.1295	45.9869	0.21753	0.29313
25	0.3977	170.00	130.1295	45.9869	0.21753	0.08741
26	0.9250	170.00	130.1295	575.7123	1.08868	1.00000
27	0.9250	110.17	128.1295	468.4747	0.91110	1.00000
28	0.4234	202.09	224.8710	81.7456	0.27347	0.30952
29	0.4234	202.87	475.6754	83.1082	0.27410	0.30952
30	0.8845	255.90	224.8710	710.7493	1.22744	0.01640
31	0.2874	255.90	224.8710	154.1442	0.36698	0.16203
32	0.2874	226.34	132.1295	154.1442	0.36895	0.16203
40	BRINE	315.00	0.0000	287.1318	0.00000	3.63361
41	BRINE	314.40	0.0000	286.5232	0.00000	3.63361
42	BRINE	231.07	0.0000	201.9769	0.00000	3.63361
43	BRINE	170.00	0.0000	140.0148	0.00000	3.63361
44	BRINE	255.71	0.0000	226.9764	0.00000	3.63361
50	AIR	51.70	14.6931	122.3092	1.62806	61.5852
51	AIR	81.92	14.6731	129.5794	1.64196	61.5852
52	AIR	82.23	14.6931	129.6517	1.64200	61.5852

Table 2.

Heat in	68,839.64 kW	534.57 Btu/lb
Heat rejected	57,375.26 kW	445.54 Btu/lb
Turbine enthalpy Drops	11,540.34 kW	89.62 Btu/lb
Gross Generator Power	11,004.29 kW	85.45 Btu/lb
Process Pumps (-2.78)	-387.64 kW	-3.01 Btu/lb
Cycle Output	10,616.65 kW	82.44 Btu/lb
Other Pumps and Fans (-4.45)	-616.65 kW	-4.79 Btu/lb
Net Output	10,000.00 kW	77.65 Btu/lb
Gross Generator Power	11,004.29 kW	85.45 Btu/lb
Cycle Output	10,616.65 kW	82.44 Btu/lb
Net Output	10,000.00 kW	77.65 Btu/lb
Net thermal efficiency		14.53% %
Second Law Limit		26.91% %
Second Law Efficiency		53.98% %

Because the total heat rejection of the system into the ambient occurs in condenser HE1, and this heat is removed only from the basic solution, it follows that the greater the mass of the recirculating stream (i.e. stream 24), the greater the additional output of power produced by the supplementary cycle. But the quantity of working fluid circulating in the supplementary cycle is limited by the heat balance in heat exchanger HE3 (i.e. by the ability of stream 5-7 to acquire heat). When the initial temperature of the geofluid (i.e. the temperature at point 40) increases, the composition of the vapor at point 16 becomes leaner (containing less of the low-boiling component), and therefore boiling stream 10-11 can fully vaporize in heat exchanger HE5. As a result, the flow rate of stream 15 becomes equal to zero, and the enrichment of the initial circulating solution with a composition as at point 24 becomes impossible. The system therefore converts into its simplified version, which is presented in figure 3. The working process of this simplified version of the system does not require a separate description.

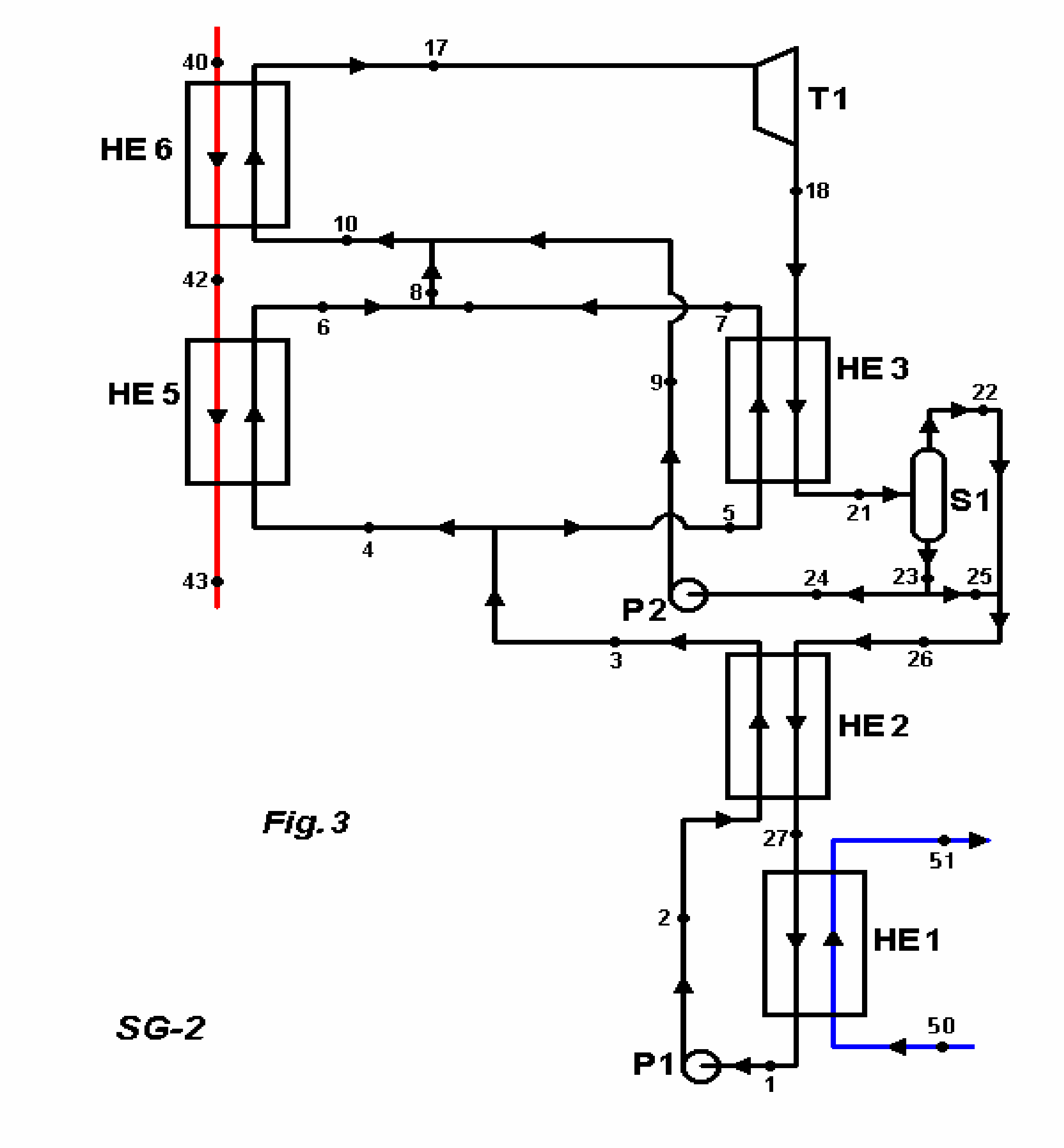

Fig.3 SG-2

For an initial temperature of the liquid portion of geofluid of 338°F. and a temperature of cooling air of (ambient) of 30°F. (parameters for Mutnovskaya geothermal power plant) the parameters of the key points of the described system are given in table 3, and the summary of its performance is given in table 4.

Table 3.

Pt.	X lb/lb	T °F	P psia	H Btu/lb	S Btu/lb•°F	G rel G/G=1
1	0.9250	50.15	82.8349	-5.4566	0.03349	1.00000
2	0.9250	51.56	498.6754	-3.0806	0.03447	1.00000
3	0.9250	165.00	478.6754	130.1713	0.26958	1.00000
4	0.9250	165.00	478.6754	130.1713	0.26958	0.59654
5	0.9250	165.00	478.6754	130.1713	0.26958	0.40346
6	0.9250	201.65	476.6754	499.9432	0.85326	0.59654
7	0.9250	201.65	476.6754	499.9432	0.85326	0.40346
8	0.9250	201.65	476.6754	499.9432	0.85326	1.00000
9	0.3229	170.56	281.2552	54.0216	0.22249	0.18050
10	0.8329	268.55	475.6754	561.1635	0.94545	1.18050
11	0.8329	321.68	474.6754	752.2914	1.19819	1.18050
14	0.9250	268.58	475.6754	652.5207	1.07311	1.00000
15	0.2998	321.68	474.6754	230.3635	0.46913	0.00000
16	0.8329	321.68	474.6754	752.2914	1.19819	1.18050
17	0.8329	329.00	473.1754	757.7151	1.20542	1.18050
18	0.8329	206.65	88.8349	653.1245	1.23321	1.18050
19	0.2998	321.68	224.7644	230.3635	0.46913	0.00000
20	0.8329	206.65	88.8349	653.1245	1.23321	1.18050
21	0.8329	170.00	86.8349	526.7465	1.04080	1.18050
22	0.9561	170.00	86.8349	641.1475	1.23853	0.95089
23	0.3229	170.00	86.8349	52.9835	0.22193	0.22961
24	0.3229	170.00	86.8349	52.9835	0.22193	0.18050
25	0.3229	170.00	86.8349	52.9835	0.22193	0.04911
26	0.9250	170.00	86.8349	612.2619	1.18860	1.00000
27	0.9250	97.06	84.8349	479.0101	0.96696	1.00000
28	0.3229	170.56	281.2552	54.0216	0.22249	0.18050
29	0.3229	171.09	476.6754	55.0365	0.22301	0.18050
30	0.9250	235.77	109.4563	742.2942	1.33875	0.00000
31	0.9250	235.77	109.4563	146.3823	0.34084	0.00000
32	0.9250	224.57	88.8349	146.3823	0.34115	0.00000
40	BRINE	338.00	0.0000	310.4676	0.00000	3.55048
41	BRINE	336.22	0.0000	308.6643	0.00000	3.55048
42	BRINE	231.23	0.0000	202.1423	0.00000	3.55048
43	BRINE	170.00	0.0000	140.0148	0.00000	3.55048
44	BRINE	273.59	0.0000	245.1160	0.00000	3.55048
50	AIR	28.58	14.6931	116.7501	1.61693	65.3274
51	AIR	59.42	14.6731	124.1661	1.63176	65.3274
52	AIR	59.71	14.6931	124.2354	1.63180	65.3274

Table 4.

Heat in	55,070.37 kW	605.19 Btu/lb
Heat rejected	43,868.74 kW	482.09 Btu/lb
Turbine enthalpy Drops	11,235.34 kW	123.47 Btu/lb
Gross Generator Power	10,713.46 kW	117.73 Btu/lb
Process Pumps (-2.75)	-270.46 kW	-2.97 Btu/lb
Cycle Output	10,443.00 kW	114.76 Btu/lb
Other Pumps and Fans (-4.53)	-442.97 kW	-4.87 Btu/lb
Net Output	10,000.02 kW	109.89 Btu/lb
Gross Generator Power	10,713.46 kW	117.73 Btu/lb
Cycle Output	10,443.00 kW	114.76 Btu/lb
Net Output	10,000.02 kW	109.89 Btu/lb

```
Net thermal efficiency                    18.16% %
Second Law Limit                          31.27% %
Second Law Efficiency                     58.08% %
```

From a comparison of operational parameters presented in tables 1 and 3 it follows that by varying the flow rate of the recirculating stream with parameters as at point 24, it is possible to adjust the operation of SG-2 to varying weather conditions. Such variations can be arranged to be executed automatically by making the flow rate of this stream dependant on the initial temperature of cooling air. As a result, this system will perform in an optimal manner in all weather conditions, significantly increasing its annual power output.

It is interesting to point out that even at an initial temperature of geofluid as high as 375°F, system SG-2 has an efficiency that is still superior by a margin of at least 4% over KCS-11. At an initial temperature of geofluid of 315, which are typical of geothermal sources currently being used, SG-2 has an efficiency which is 25% higher than KCS-11. As a result of the high efficiency of SG-2, it specific capital cost is significantly reduced as compared to KCS-11.

A project study undertaken by an independent third party showed that for the same heat source, SG-2 would produce 26%-27% more power and have specific cost per installed kilowatt that is 28% lower than KCS-11.

It must be noted that KCS-11 in its own turn, has an efficiency which is 25%-35% higher and a cost which is 25%-30% lower than systems utilizing an Organic Rankine Cycle.

3. CONCLUSION

SG-2, developed by Kalex, LLC., has substantially higher efficiency and lower costs than any known alternative systems. SG-2 is self-adjusting to variations in weather conditions and to changes in the initial temperature of geofluid resources (such as the gradual decrease in geofluid temperature observed over the course of years of utilization of a geothermal source). SG-2 has been chosen as an operational system for several projects now in development, and is currently available for licensing to interested parties.