KALEX LLC.

Superior Efficiency
Reduced Costs
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Kalex
Kalina Cycle Power Systems
For Use as a Bottoming Cycle for Combined Cycle Applications

Kalex LLC's Kalina Cycle for Bottoming Cycle Applications

Contents:

Kalex LLC's Kalina Cycle
for Bottoming Cycle Applications

Kalex LLC has developed a set of power system that greatly improve the efficiency of bottoming cycles for combined cycle systems.

Bottoming cycles for combined cycle systems were the first application for the original Kalina Cycle. power systems designed for use as bottoming cycle in combined cycle systems were the first applications of the original Kalina Cycle. An experimental plant utilizing a simplified version of a Kalina Cycle bottoming cycle was built and operated successfully in Conoga Park, California on the premises of ETEC of the DoE.

Combined cycle systems represent a major source of electrical generation capacity world wide and any cost effective increase in efficiency can deliver very large economic advantages.

Currently, using a new generation of more efficient gas turbines, combined cycle systems with conventional triple pressure Rankine cycles as bottoming cycles attain overall efficiencies on the order of 55% to as high as 59%.

Kalex LLC has developed new generation of Kalina Cycle systems for use in high temperature applications, and in particular a new set of systems for use as bottoming cycles of combined cycle systems.

Kalex LLC offers two new systems for bottoming cycle applications in combined cycle power systems. These two new systems are designated SBC-16 and SBC-17 (where "SBC" stands for System, Bottoming Cycle.) Both systems are capable of providing a substantial improvement in the overall efficiency of the bottoming cycle of a combined cycle system, allowing for overall combined cycle efficiencies in excess of 61 or 62%.

Kalex's calculations have shown that the thermal efficiency of these bottoming cycle systems is on order of 40 to 41% as compared to a thermal efficiency of approximately 34.5% for a triple pressure Rankine cycle. The Second Law efficiencies of these systems is in the range of 80.8 to 83.3%.

Likewise when compared to earlier generations of Kalina Cycle systems for bottoming cycles in a combined cycle power system, these new Kalex systems are more efficient and more cost effective.

For instance, one of the key features of the Exergy Kalina Cycle system for bottoming cycles, KCS-6, was the recuperative intercooling of the working fluid between the intermediate and low pressure turbines. However, the dedicated intercooler heat exchanger in which this operation took place was costly and acted as a drawback in the design.

In the new Kalex systems for bottoming cycles, the intercooling process is designed to occur directly in the boiler (HRVG or Heat Recovery Vapor Generator.) As a result, the intercooling process in the new Kalex systems did not require any special and expensive apparatus.

Because these systems operate with a water-ammonia working fluid, the can be susceptible to nitridation caused by the water-ammonia working fluid. Therefore, a process for the prevention of nitridation is part of the Kalex technology for bottoming cycles for combined cycle power systems.

--A description of Kalex's method for prevention of nitridation is given in appendix B.

Thus, the paramount problem needing to be solved for the application of a Kalina Cycle to bottoming cycle applications (and to high temperature applications in general) was to prevent nitridation in the water-ammonia working fluid environment.

After extensive theoretical and experimental investigation, AMR LLC developed and patented a method of preventing nitridation in a water-ammonia working fluid environment.

Based on this method, Kalex LLC, (which has full rights to use and market the technology developed by AMR LLC,)

SBC-16 uses three turbine stages (a high pressure, intermediate pressure and low pressure turbine, or HPT, IPT and LPT.) SBC-17 uses only two turbine stages (a high pressure and an intermediate pressure turbine, or HPT and IPT.)

The use of only two turbine stages in SBC-17 is possible due to the development of a new condensation and thermal compression subsystem with improved efficiency, designated CTCSS-28 (where CTCSS stands for Condensation Thermal Compression Subsystem.)

SBC-17 has a very slightly lower overall efficiency than SBC-16 but provides a substantial cost savings compared to SBC-16.

In distinction from Rankine Cycle systems, Kalina Cycle systems, including the Kalex systems SBC-16 and SBC-17, are sensitive to the initial temperature of cooling water. In a Rankine Cycle system, the temperature and therefore the pressure of condensation is determined by the final temperature of the cooling water and the process of condensation occurs at a constant temperature. In a Kalina Cycle, the process of condensation occurs at variable temperatures and the pressure of condensation is determined by the initial temperature of the cooling water.

Therefore it is highly advantageous for a Kalina Cycle to use the lowest possible initial temperature of cooling water.

The Kalex SBC-16 and SBC-17 systems can also be used with conventional cooling towers or even with one-through cooling, and still provide substantial improvements in overall efficiency.

The high efficiency of Kalex's SBC systems is based on the advantages of using a variable composition, multi-component working fluid. The use of a water-ammonia working fluid allows Kalex systems to operate with conventional components, steam turbines and heat exchanger apparatus; Kalex systems require only proven "off-the-shelf" components. By avoiding the use of experimental or specialized high cost components, Kalex systems maximize reliability while minimizing costs and technological risks.

The SBC systems are projected to be highly cost effective. The higher efficiency of the system's operation allows for cost reductions in heat exchangers and other apparatus; the high efficiency does not come from the use of expensive components.

(For example, the condensers required for the CTCSS-28a subsystem are substantially smaller in size and lower in cost than conventional vacuum condensers used in a Rankine Cycle system.)

Likewise, it should be noted that the many of the multiple heat exchangers in CTCSS-28a are in fact computational conventions; in actual fact, the CTCSS-28a subsystem uses only four heat exchangers; (HE1 and HE2 and HE3 as shown in the flow diagram of CTCSS-28a are actually a single heat exchanger, and are separated in the conceptual flow diagram for computational purposes. Likewise HE5 and HE6 comprise a single actual heat exchanger.)

The proposed Kalex systems, SBC016 and SBC-17, provide very substantial increases in the overall efficiency and power output of a combined cycle power system.

> **--A table of performance data, calculated for several gas turbines and several cooling water --temperatures, is presented in table 1.**
>
> **--A conceptual flow diagram of SBC-16 is given in figure 1.**
> **--A conceptual flow diagram of SBC-17 is given in figure 2.**
> **--A conceptual flow diagram of the CTCSS-28a subsystem is given in figure 3.**
> (Note that the CTCSS-28a subsystem is used with both SBC-16 and SBC-17.)
>
> **--The operations of SBC-17, SBC-16 and CTCSS-28 are described in appendix A.**

Complete heat and mass balances for both systems are available upon request.

Appendix A: SBC-16, SBC-17 and CTCSS-28a

The Kalex SBC systems are both comprised from two sub-systems, a boiler-turbine sub-system in which the thermal energy of the gas turbine exhaust is converted into power, and a condensation thermal compression sub-system (CTCSS) in which the working fluid is condensed at reduced pressure (i.e., at pressure which is lower than the pressure of condensation achievable at any given ambient temperature.)

The systems use a variable composition multi-component (two component) working fluid. One of the components (the "low boiling" component) has a substantially lower normal boiling temperature than the other ("high bollixing") component. In the preferred embodiment of the proposed system, ammonia is the low boiling component and water is the high boiling component. This working fluid also includes an additive to inhibit high temperature corrosion from nitridation, which is possible with the ammonia component.

The working fluid is designated as a "rich solution" when it contains a high proportion of low-boiling component and as a "lean solution" when it contains a low proportion of the low-boiling component.

SBC-17:

SBC-17 is shown in a flow diagram in **figure 1** and operates as follows:

Two streams of working fluid exit the CTCSS, having parameters as a points 29 and 49. The stream at point 29 has a composition which is richer than the composition of the working fluid that circulates through the system's turbines (see below.) The stream at point 49 has a composition that leaner than the composition of the working fluid that circulates through the system's turbines (see below.) Both streams are in a state of subcooled liquid.

Streams 29 and 49 are now sent into parallel feed pumps, FP1 and FP2 correspondingly, where they are pumped to a required high pressure, and obtain parameters as at points 100 and 120 respectively. The streams at points 100 and 120 are in a state of subcooled high pressure liquid. The pressures at points 100 and 120 are equal or close to equal.

Stream 100 is designated as the "rich" stream and stream 120 is designated as the "lean" stream.

Streams 100 and 120 then enter into the heat recovery vapor generator, HRVG, in which they are heated by a stream of hot gas turbine exhaust flue gasses with initial parameters as at point 600 (see below.)

In the HRVG, streams 100 and 120 are heated, and obtain initial parameters as at points 113 and 123 correspondingly. Then streams 113 and 123 are further heated obtaining parameters as at points 101 and 121 correspondingly.

The section of the HRVG in which processes 100-101 and 120-121 occur is designated as the pre-heater section.

Thereafter, streams 101 and 121 are further heated as they pass through the HRVG, obtaining parameters as at points 114 and 124 respectively. Thereafter, streams 114 and 124 are yet further heated, obtaining parameters as at points 112 and 122 correspondingly.

In the preferred embodiment of the system, both the rich and lean streams of working fluid are at supercritical pressure; i.e., a pressure which is higher than the respective critical pressures of those streams.

In process 101-112, the rich composition stream is converted from a liquid to a vapor state. In process 121-122, the lean composition stream mostly remains in liquid form.

Thereafter, streams 112 and 122 are combined, forming a stream of working fluid with parameters as at point 111, corresponding to a state of vapor.

The purpose of this arrangement (of two streams of working fluid with different compositions) provides that the overall conversion of working fluid from liquid to vapor occurs at lower temperatures than would be the case if a single combined stream of working fluid were introduced into the HRVG. (--this constitutes an important basic claim for this application--)

The two substreams are combined at such a point that the temperature of the combined stream at point 111 is practically the same as the temperatures at points 112 and 122.

Thereafter, the combined stream with parameters as at point 111 is further heated and obtains parameters as at point 102.

The section of the HRVG in which processes 101-112, 121-122 and 111-102 occur is designated as the intercooler section of the HRVG.

In the intercooler section of the HRVG, the upcoming streams of working fluid 101-112 and 121-122 are heated not only by the stream of hot flue gas, 600-609 (see below,) but also by an intercooling stream of returning working fluid, 107-108, (see below.)

Points 114 and 124 correspond to points in the process at which the temperature difference in between the heating stream of flue gas (at point 610) and the streams of working fluid (points 114 and 124) reaches its minimum; (the so-called pinch point.)

Thereafter, the stream of working fluid with parameters as at point 102 is further heated by the stream of flue gas, obtaining parameters as at point 103. This section of the HRVG is designated as the midsection of the HRVG.

Thereafter, stream 103 passes through the high temperature section of the HRVG, designated as the super-heater / re-heater section of the HRVG and obtains parameters as at point 104 corresponding to a state of high pressure, high temperature superheated vapor.

The stream of flue gas from the gas turbine with initial parameters as at point 600 (see above,) passes through the super-heater / re-heater section of the HRVG where it is cooled and obtains parameters as at point 603, transferring heat to the working fluid in process 103-104.

Thereafter stream 603 passes through the midsection of the HRVG, where it is cooled, transferring heat to the working fluid (process 101-103) and obtains parameters as at point 607.

Thereafter stream 607 passes through the intercooler section of the HRVG, where it is further cooled, transferring heat to the working fluid (in process 101-112, 121-122 and 111-102,) obtaining intermediate sequential parameters as at points 615 ands 610, and finally obtains parameters as point 608, (see above.)

In process 607-615-610-608 the flue gas is not only cooled by the upcoming streams of working fluid, but at the same time is partially heated the intercooling stream of working fluid, 107-115-110-108, (see below.)

Thereafter, the stream of flue gas with parameters as at point 608 passes through the pre-heater section of the HRVG where it cooled, transferring heat to the upcoming streams of working fluid (100-101 and 120-121,) obtains intermediate parameters as at point 613, and finally is further cooled, obtaining parameters as at point 609. Stream 609 is then released into the stack.

At point 613, the flue gas reaches the state of its dew point; i.e., the state at which condensation of water vapor which is part of the flue gas begins. As a result, the parameters of the flue gas at point 609 correspond to a state of wet gas.

Meanwhile, stream 104 exits the HRGV and passes through an admission valve, TV, where its pressure is reduced, obtaining parameters as at point 109. Stream 109 now enters into a high pressure turbine, HPT, where it is expanded, producing power, and obtains parameters as at point 106.

Stream 106 is now sent back into the HRVG where it passes through the super-heater / re-heater section of the HRVG, is reheated, and obtains parameters as at point 105.

Stream 105 is now sent into the intermediate pressure turbine, IPT, where it is expanded, producing power, and obtains parameters as at point 107.

Stream 107 is now again sent back into the HRVG, into the intercooler section of the HRVG, where it is cooled in process 107-115-110-108, transferring heat to the flue gas in the intercooler section of the HRVG (see above,) and exiting the HRVG having parameters as at point 108.

Stream 108 is now re-designated as point 138 prior to being sent, having parameters as at point 138, into the Condensation Thermal Compression Subsystem (CTCSS.)

In SBC-17, all expansion occurs in two turbines, HPT and IPT.

After being cooled in the intercooler section of the HRVG, the working fluid none-the-less remains in a state of superheated vapor.

The use of two streams of working fluid with different compositions in the proposed system, (see above,) allows the working fluid in the intercooler section of the HRVG to go from liquid to vapor at a lower temperature than would be possible with a single combined stream of working fluid.

This, in turn, allows for expansion to occur in the turbines at a higher temperatures and therefore increases the total useful power produced per unit of weight of working fluid.

SBC-16:

SBC-16, an alternate and somewhat more complex version of SBC-17, involves the addition of an extra turbine. In this alternate version, (shown in **figure 2**,) the stream of working fluid, with parameters as at point 108, exiting from the intercooler section of the HRVG is sent into a low pressure turbine, LPT, where it is expanded, producing additional power, and obtaining parameters as at point 138. Stream 138 is then sent into the CTCSS.

In the case that fully expanded working fluid were to be sent into a simple condenser, cooled by air or water (as opposed to being sent into the CTCSS,) the pressure at point 138 would be defined by the required pressure of condensation of the chosen working fluid at the temperature of the cooling media in the condenser.

In the proposed system, stream 138 is sent into the CTCSS, where the remaining thermal energy potential of this stream is used to provide for its own condensation at pressures that are substantially lower than the pressure that could be achieved in a simple condenser.

As a result, the total rate of expansion of the working fluid is substantially increased, which results in the increased efficiency of the proposed system.

In addition, in the proposed system, the CTCSS splits the single stream of working fluid into two substreams with different compositions, (as described above.)

CTCSS-28a:

The CTCSS (designated as CTCSS-28a) is shown in **figure 3** and operates as follows:

A stream of expanded working fluid, with parameters as at point 138, which, in most cases, is in a state of superheated vapor, is mixed with a stream of lean liquid, having parameters as at point 71, (see below.) As a result of this mixture, the composition of the new combined stream is leaner than that of stream 138. The flow rate of stream 71 is chosen in such a way that, as a result of mixing, the resultant stream obtains parameters as at point 38, corresponding to a state of saturated vapor.

In the case that the vapor at point 138 is already in a state of saturated vapor, the flow rate of stream 71 is equal to 0 and the parameters at points 138 and 38 are the same.

Stream 38 now enters into a heat exchanger, HE1, where it is partially condensed, releasing heat for process 11-5, (see below,) and obtains parameters as at point 15.

At this point, an additional stream of lean liquid with parameters as at point 8, (see below,) is mixed with stream 15. As a result the combined stream, with a larger flow rate, having parameters as at point 16, is formed. The composition at point 16 is substantially leaner than at point 15.

Stream 16 now enters into a heat exchanger, HE2, where it further cooled and condensed, releasing heat for process 12-11, (see below,) and obtains parameters as at point 17, corresponding to a state of a vapor-liquid mixture.

Thereafter stream 17 enters into a heat exchanger, HE3, where it is yet further cooled and condensed, providing heat for process 44-14, (see below,) and obtains parameters as at point 18.

Stream 18 is then mixed with a stream of lean liquid having parameters as at point 41, forming a stream with parameters as at point 19. The composition of stream 19 is designated as a "basic solution" composition. The composition of the basic solution at point 19 is chosen in such a way that it can be fully condensed by the cooling media (air or water) at the available temperature of the cooling medium.

Stream 19 now passes through a final low pressure condenser, HE4, where it is cooled in counter-flow with a stream of cooling media, 52-53, and fully condensed, obtaining parameters as at point 1.

Stream 1 is now sent into a circulating pump, P1, where it is pumped to an intermediate pressure and obtains parameters as at point 2, corresponding to a state of subcooled liquid.

Thereafter, stream 2 is mixed with a stream of rich vapor having parameters as at point 39, (see below,) and obtains parameters as at 24, referred to as an enriched basic solution.

Stream 24 is now sent into a circulating pump, P4, where it is pumped to a required elevated pressure, obtaining parameters as at point 20, corresponding to a state of subcooled liquid. The pressure at point 20 is higher than the pressure at which the working fluid circulating through the turbines in the SBC system could be condensed by the cooling media at the available temperature.

Thereafter, stream 20 is divided into two substreams with parameters as at points 36 and 44. Stream 44 represents the substantially greater part of the flow of stream 20.

Stream 44 now enters into HE3, where it is heated in counterflow by the condensing stream 17-18 and obtains parameters as at point 14, corresponding to a state of saturated or slightly subcooled liquid, (see above.)

Stream 14 is now divided into two substreams, having parameters as at point 22 and 13.

Stream 22 is then further divided into two more substreams, having parameters as at points 12 and 21.

The stream if enriched basic solution with parameters as at point 12 is now sent into HE2, where it is heated and partially vaporized in counterflow with the stream of condensing working fluid, 16-17, and obtains parameters as at point 11, corresponding to a state of vapor-liquid mixture, (see above.)

Stream 11 now enters into HE1, where it is further heated and vaporized in counterflow by stream 38-15, (see above,) and obtains parameters as at point 5, corresponding to a state of vapor-liquid mixture.

Stream 5 is now sent into a gravity separator (flash tank) S1, where it is separated into a stream of saturated vapor with parameters as at point 6 and a stream of saturated liquid with parameters as at point 7.

The composition of the saturated vapor at point 6 is substantially richer than the composition at point 5, and likewise substantially richer than the composition of the working fluid circulating through the turbines of the SBC system (with parameters as at point 138.)

The composition of the saturated liquid at point 7 is, to the contrary, substantially leaner than the composition at point 5.

The stream of lean saturated liquid with parameters as at point 7 is now divided into two substreams having parameters as at points 70 and 4.

Stream 70 is now sent into a throttle value, TV7, where its pressure is reduced to a pressure equal to the pressure at point 138, and obtains parameters as at point 71. Stream 71 is now mixed with stream 138, reducing its temperature and forming a stream of saturated vapor with parameters as at point 38, (see above.)

Meanwhile, the stream of saturated vapor with parameters as at point 6 (coming from S1,) is sent into a scrubber, (direct contact heat exchanger,) SC1.

At the same time, stream 21 (see below,) passes through a throttle valve, TV6, where its pressure is slightly reduced, and obtains parameters as at point 10. Stream 10 is now sent into SC1.

Stream 6 (vapor) and stream 10 (liquid) move through SC1 in counterflow to each other.

As a result of interaction between streams 6 and 10, a stream of further-enriched saturated vapor having parameters as at point 30 is removed from the top of SC1.

At the same time a stream of saturated liquid with parameters as at point 35 is removed from the bottom of SC1.

Stream 35 is now combined with stream 4, forming a stream of liquid a stream of lean liquid with parameters as at point 9. Stream 9 is then sent into a throttle value, TV1, where its pressure is reduced and obtains parameters as at point 8. The pressure and temperature at point 8 are equal to the pressure and temperature at point 15, (see above.)
Streams 8 and 15 are now combined to form stream 16, (see above.)

At the same time, stream 13 (see above,) is sent into a throttle valve, TV2, where its pressure is reduced to an intermediate pressure, and obtains parameters as at point 43, corresponding to a state of a liquid-vapor mixture.

Stream 43 now enters into a gravity separator, S2, where it is separated into a stream of saturated vapor with parameters as at point 34, and a stream of saturated liquid with parameters as at point 32.

Concurrently, the stream of enriched basic solution with parameters as at point 36, (see above,) is sent into a throttle valve, TV5, where its pressure is reduced to a level equal to the pressure at point 34, and obtains parameters as at point 31, corresponding to a state of liquid-vapor mixture. Stream 31 is now combined with stream 34, forming a stream with parameters as at point 3.

The pressure and composition at point 3 are such that stream 3 can be fully condensed with the available cooling media.

Stream 3 is now sent into an intermediate pressure condenser, HE7, where it is cooled in counterflow and fully condensed by a stream of cooling media, 56-57, and obtains parameters as at point 23. The flow rate and composition of stream 23 are such that if it would be combined with the stream of vapor with parameters as at point 30, it would form a stream with the same composition and flow rate as the stream at point 138.

Meanwhile, stream 30 (exiting from the top of SC1,) is sent though a heat exchanger, HE5, where it is cooled and partially condensed, obtaining parameters as at point 25.

At the same time, stream 23 is sent into a circulating pump, P2, where its pressure is increased to a pressure equal to the pressure at point 25, and obtains parameters as at point 40.

Stream 40 is now divided into two substreams, with parameters as at points 45 and 46.

Stream 45 is now combined with stream 25, forming a stream with parameters as at point 26. The composition at point 26 is equal to the composition of the rich working solution that will be sent (as stream 29 of the SBC system) into the HRVG.

Thereafter, stream 26 is sent into a high pressure final condenser, HE6, where it is cooled and fully condensed in counterflow by a stream of cooling media, 54-55, and obtains parameters as at point 27.

Stream 27 is then sent into a booster pump, P3, where its pressure is increased, obtaining parameters as at point 28, corresponding to a state of subcooled liquid.

Stream 28 (rich working solution) now passes through HE5, where it is heated by condensing stream 30-25 (see above,) and obtains parameters as at point 29. Stream 29 is now sent into the SBC system.

Meanwhile, stream 46 is sent into a booster pump, P5, where its pressure is increased to an elevated pressure, obtaining parameters as at point 48.

Stream 48 is then sent into HE5, where it is heated in counterflow by condensing stream 30-25 (see above,) and obtains parameters as at point 49. Stream 49 is now sent into the SBC system.

Meanwhile, the stream of liquid exiting S2, with parameters as at point 32, is sent into a throttle valve, TV3, where its pressure is reduced, and obtains parameters as at point 42, corresponding to a state of vapor-liquid mixture.

Stream 42 is now sent into a gravity separator, S3, where it is separated into a stream of saturated vapor with parameters as at point 39 and a stream of saturated liquid with parameters as at point 47.

Stream 39 is now mixed with stream 2 (see above,) is fully absorbed by stream 2 (which is a stream of basic subcooled basic solution liquid) and forms a stream of enriched solution with parameters as at point 24 (see above.)

Stream 47 meanwhile (liquid exiting S3) is sent into a throttle valve, TV4, where its pressure is reduced, and obtains parameters as at point 41. Stream 41 is then combined with stream 18, forming a stream of basic solution with parameters as at 19 (see above.)

The cooling media (coolant; air or water) with initial parameters as at point 50 is sent into a pump, P7, where its pressure is increased, obtaining parameters as at point 51. (In the case that the coolant is air, a fan replaces P7.)

Stream 51 is then divided into three parallel streams with parameters as at point 52, 54 and 56. Streams 52, 54 and 56 are then sent into heat exchangers HE4, HE7 and HE6 correspondingly, (as described above.)

Throttling of stream 32, (a stream of liquid,) and then sending the resultant stream 42 into S3 in order to produce a stream of vapor with parameters as at 39 allows for the enrichment of the basic solution, which in its turn allows for the initial basic solution to be made leaner.

As a result, the pressure at which the basic solution can be condensed becomes lower and therefore the back pressure to which the working fluid can be expanded in the turbines becomes lower as well, increasing the output and efficiency of the system.

This variant of the CTCSS, (CTCSS-28a,) also provides for the division of the exiting working fluid into two substreams, which allows the reduction of the average temperature at which the working fluid is converted from liquid to vapor in the HRVG (as described above.)

Components:

In the standard embodiment of a bottoming cycle for combined cycle units, the boiler (i.e., HRVG or HRSG) usually consists of a heat exchanger though which tubes pass in an "S" pattern. As a result, heat transfer from the flue gas to the working fluid occurs in a counter-cross flow. Tubes through which the working fluid moves through the HRVG or HRSG form rows.

In the systems described, in the preheater section of the HRVG, there are two working fluid flows. In the preferred embodiment of the HRVG's preheater, each row of tubes should be comprised of tubes for both rich and lean working solution, placed intermittently in the row.

In the intercooler section, there are two subsections; the lower temperature portion of the intercooler, where the working fluid moves as two streams in separate tubes, and the higher temperature portion, where the working fluid has been combined into single stream.

In addition, the intercooler also contains the tubes through which the intercooled working fluid flows.

Therefore, each row of tubes in the lower temperature intercooling section is comprised of three kinds of tubes; two through the two streams of high pressure working fluid (rich and lean streams) are moving counter-crosswise to the flow of flue gas, and one though which the intercooling working fluid is moving parallel-crosswise to the flow of the flue gas.

In the higher temperature portion of the intercooler, each row of tubes consists of two sets of tubes; high pressure tubes in which the combined stream of working fluid is moving counter-crosswise to the flow of flue gas, and low pressure tubes through which the intercooling working fluid is moving parallel-crosswise to the flow of the flue gas.

In the CTCSS, heat exchangers HE1, HE2, HE3 and HE4 can arranged as a single combined heat exchanger with four sections through which the condensing stream passes through the shell and the upcoming heated streams move through their respective tube coils or flow passages.

Heat exchangers HE5 and HE6 of the CTCSS can also be arranged as a single heat exchanger with two sections.

Appendix B:
Prevention of Nitridation

Nitridation (or nitriding) occurs as a catalytic heterogenic process in which metal serves as the catalyst.

In Kalina Cycle applications that use a water-ammonia working fluid, nitridation is thought to cause degradation of metal parts, in particular turbine blades, making metal brittle and prone to breakage.

In low temperature applications, water acts as catalytic poison, preventing nitridation at temperatures up to 750 °F (400 °C.) However, once operating temperatures climb above this temperature, water no longer prevents nitridation. Up till now, this has precluded the use of water-ammonia power cycles with operational temperatures higher than 750 °F (400 °C.)

In Kalex high temperature systems, a patented process is used to prevent nitridation by means of adding a catalytic poison to the working fluid.

After more than 3 years of analysis and experimentation, with more than 1,000 samples of materials and catalytic poisons tested to 1,100 °F (higher than the operating temperature of Kalex high temperature power systems), it was determined that sulfur acts as catalytic poison up to 1100 °F. In theory, sulfur should continue to act as a catalytic poison up to 2800°F (1540 °C).

Sulfuric corrosion is **not** a risk using this method because the concentration of sulfur used is far below threshold concentration at which sulfuric corrosion can begin to occur. None the less, additional catalytic poisons may be added to secure against any hypothetical possibility of sulfur corrosion

The total operational cost of this method is extremely low, and does not negatively impact the economic viability of Kalex technology.

Kalex has exclusive rights to this patented method (subject to U.S. Patent 6,482,272 B2) and offers this anti-nitridation technology as part of the Kalex technological package.

More information can be had in Kalex's detailed report on prevention of nitridation in Kalina Cycle systems, available upon request.

Figure 1: SBC-16

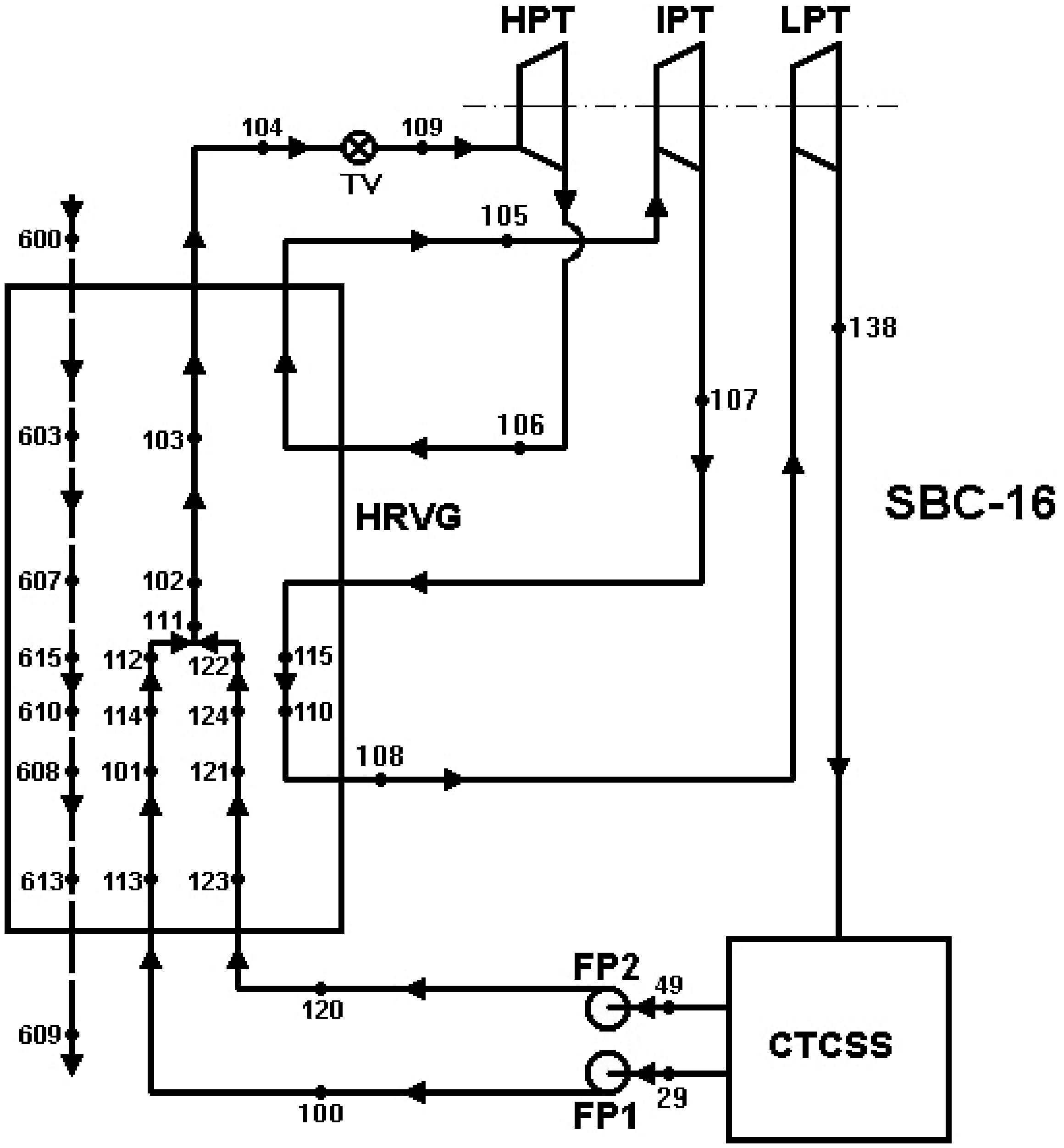

Figure 2: SBC-17

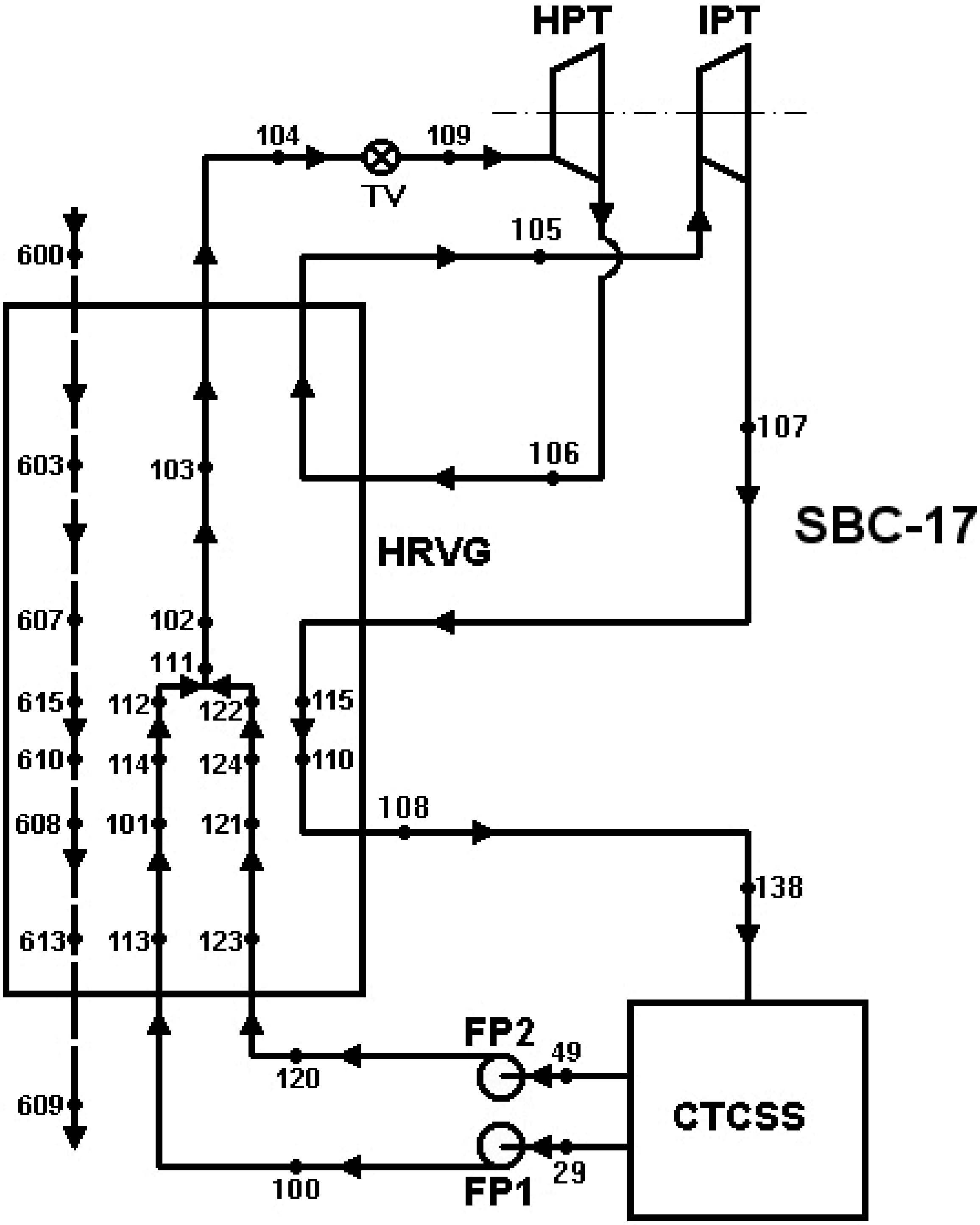

Figure 3: CTCSS-28a

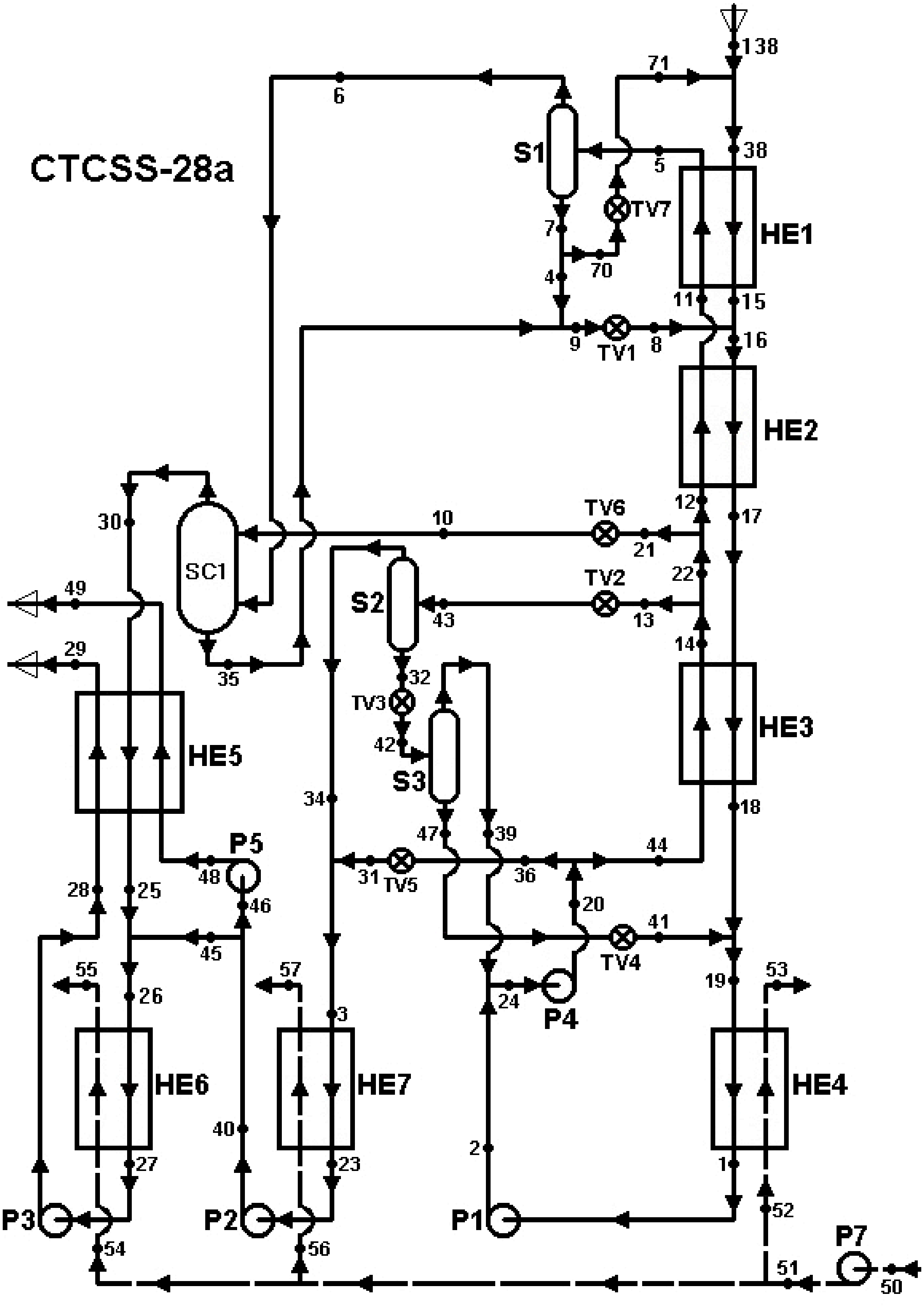

Table 1: **Kalex Bottoming Cycle Comparison Chart: SBC-16 with CTCSS-28a.**

Gas Turbine			Bottoming Cycle				Combined Cycle		Cooling Water Temperature	Incremental Output
Type	Output	Efficiency	Type	Output	Efficiency	2nd Law Efficiency	Output	Efficiency		
Alstom GT26	287,838 kW	39.6%	3P Rankine	141,012 kW	33.68%	69.04%	428,850 kW	59.00%	56.0 °F	baseline
"	287,838 kW	39.6%	SBC-16	163,058 kW	39.44%	80.68%	450,896 kW	62.03%	56.0 °F	+22,046 kW
"	287,838 kW	39.6%	SBC-16	164,265 kW	39,63%	81.24%	452,103 kW	62.20%	53.5 °F	+23,253 kW
"	287,838 kW	39.6%	SBC-16	168.851 kW	40.38%	83.37%	456,689 kW	62.83%	44.0 °F	+27,839 kW
G.E. 9FB	292,000 kW	38.21%	3P Rankine	155,080 kW	34.56%	69.57%	447,080 kW	58.50%	56.0 °F	baseline
"	292,000 kW	38.21%	SBC-16	180,080 kW	40.25%	80.83%	472,080 kW	61.77%	56.0 °F	+25,000 kW
"	292,000 kW	38.21%	SBC-16	181,320 kW	40.43%	81.35%	473,320 kW	61.93%	53.5 °F	+26,240 kW
"	292,000 kW	38.21%	SBC-16	185,990 kW	41.11%	83.31%	477,990 kW	62.54%	44.0 °F	+30,910 kW
Siemens SGT5-4000F	288,000 kW	39.76%	3P Rankine	135,000 kW	32.62%	67.83%	423,000 kW	58.40%	56.0 °F	baseline
"	288,000 kW	39.76%	SBC-16	157,675 kW	38.27%	80.54%	445,675 kW	61.53%	56.0 °F	+20,675 kW
"	288,000 kW	39.76%	SBC-16	158,856 kW	38.46%	81.10%	446,856 kW	61.69%	53.5 °F	+23.856 kW
"	288,000 kW	39.76%	SBC-16	163,237 kW	39.16%	83.20%	451,237 kW	62.30%	44.0 °F	+28,237 kW

Table 2: **Kalex Bottoming Cycle Comparison Chart: SBC-17 with CTCSS-28a.**

Gas Turbine			Bottoming Cycle				Combined Cycle		Cooling Water Temperature	Incremental Output
Type	Output	Efficiency	Type	Output	Efficiency	2nd Law Efficiency	Output	Efficiency		
Alstom GT26	287,838 kW	39.6%	3P Rankine	141,012 kW	33.68%	69.04%	428,850 kW	59.00%	56.0 °F	baseline
"	287,838 kW	39.6%	SBC-17	162,442 kW	39.37%	80.30%	450,280 kW	61.95%	56.0 °F	+21,430 kW
"	287,838 kW	39.6%	SBC-17	163,418 kW	39,52%	80.76%	451,256 kW	62.08%	53.5 °F	+22,408 kW
"	287,838 kW	39.6%	SBC-17	166,741 kW	40.06%	82.40%	454,579 kW	62.54%	44.0 °F	+25,729 kW
G.E. 9FB	292,000 kW	38.21%	3P Rankine	155,080 kW	34.56%	69.57%	447,080 kW	58.50%	56.0 °F	baseline
"	292,000 kW	38.21%	SBC-17	179,242 kW	40.18%	80.49%	471,242 kW	61.66%	56.0 °F	+24,162 kW
"	292,000 kW	38.21%	SBC-17	180,304 kW	40.35%	80.94%	472,304 kW	61.80%	53.5 °F	+25,224 kW
"	292,000 kW	38.21%	SBC-17	184,253 kW	40.92%	82.60%	476,253 kW	62.32%	44.0 °F	+29.173 kW
Siemens SGT5-4000F	288,000 kW	39.76%	3P Rankine	135,000 kW	32.62%	67.83%	423,000 kW	58.40%	56.0 °F	baseline
"	288,000 kW	39.76%	SBC-17	155,317 kW	38.00%	79.45%	443,317 kW	61.20%	56.0 °F	+20,317 kW
"	288,000 kW	39.76%	SBC-17	156,186 kW	38.12%	79.86%	444,186 kW	61.33%	53.5 °F	+21,186 kW
"	288,000 kW	39.76%	SBC-17	160,299 kW	39.14%	81.92%	448,299 kW	61.88%	44.0 °F	+25,299 kW