New Kalina Cycle Systems for Biomass Applications

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ABSTRACT

Kalex LLC has developed new Kalina cycle systems for the utilization of biomass as a fuel. These systems have drastically increased efficiency compared to Rankine cycle. Projected costs of these systems is substantially lower, per kilowatt, than for a Rankine cycle system. This changes the fundamental economics of biomass power, allowing for cost-effective utilization of non-gasified biomass fuel for power generation

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1 Overview of Kalex System CS-21

The core system, designated CS-21, is designed for the utilization of heat sources with initial temperatures from 1076 to 400 deg. F. in power plants of up to 50mW. A flow diagram of system CS-21 is presented in **figure 1** (attached.)

This system utilizes a multi-component variable composition (water-ammonia mixture) working fluid. Utilization of a multi-component variable composition working fluid allows for superior efficiency as compared to conventional, Rankine power systems. Using a water-ammonia working fluid allows the system to operate with conventional steam turbines and heat exchanger apparatus, thereby avoiding the technological risks associated with experimental components and reducing costs per installed kilowatt.

1.1 System Description

The system operates as follows:

Fully condensed working fluid (basic solution,) with parameters as at point 1, is pumped by a feed pump, P1, to required high pressure, and obtains parameters as at point 2. The stream with parameters as at point 2 then passes through a heat exchanger (preheater), HE2, in counterflow with a returning stream 26-27, (see below) and obtains parameters as at point 3, corresponding to a state of saturated or slightly subcooled liquid.

The stream with parameters as at point 3 then passes through recuperative boiler-condenser, HE3, where it is heated and vaporized in counterflow with a returning condensing stream 11-14, (see below,) obtaining parameters as at point 8, which corresponds to a state of wet vapor.

Meanwhile a stream of lean saturated liquid with parameters as at point 24 (see below) enters into a pump, P2, where it is pumped to a required high pressure, and obtains parameters as at point 9. Stream 9 is then sent into a heat exchanger, HE4, where it is heated in counterflow with a condensing stream, 12-13, (see below,) and obtains parameters as at point 10.

Stream 8 passes through a heat exchanger, HE5, where it is heated in counterflow by a stream of de-superheating vapor, 30-31, and obtains parameters as at point 4.

Stream 10 is meanwhile sent into a heat exchanger, HE6, where it is heated in counterflow, and partially vaporized by a stream of de-superheating vapor, 32-33, and obtains parameters as at point 5, corresponding to a state of a vapor-liquid mixture.

Thereafter, streams 4 and 5 are combined, forming a stream of working solution with parameters as at point 7, corresponding to a state of a liquid-vapor mixture.

Stream 7 is then sent into a gravity separator, S2, where it is separated into a stream of saturated vapor with parameters as at point 6 and saturated liquid with parameters as at point 35.

Streams 6 and 35 are then sent through a heat recovery vapor generator, HRVG, where they are heated in counterflow by a stream of heat source flow *(flue gas or other heat source,)* 500-502 (see below,) and obtain parameters as at point 16 and 15 respectively, which correspond (for both) to a state of superheated vapor.

Thereafter streams 15 and 16 are combined, forming a stream of superheated vapor with parameters as at point 17.

Stream 17 then passes through a turbine, T1, where it expands, producing power and obtains parameters as at point 18. The stream at point 18 is in a state of a superheated vapor.

Thereafter the returning stream 18 is divided into two substreams with parameters as at point 30 and 32 respectively. Streams 30 and 32 then pass through heat exchangers HE5 (for stream 30) and HE6 (for stream 32) respectively, where they are both cooled and almost completely de-superheated, providing heat for processes 8-4 and 10-5 respectively (see above,) obtaining parameters as at point 31 (from stream 30) and 33 (from stream 32) respectively. Stream 31 and 33 are then combined forming a stream with parameters as at point 19.

It should be noted that, in an alternate embodiment of the system, streams 10 and 8 can be sent in parallel into a single, dual flow heat exchanger. In such a case stream 18 is not divided, but is instead sent in counterflow to both stream 10-5 and stream 8-4 in the dual flow heat exchanger, exiting with parameters as at point 19.

Stream 19 is in a state of slightly superheated vapor. At this point, stream 19 is mixed with a stream of liquid having parameters as at point 29 (see below,) forming a stream of saturated vapor with parameters as at point 20.

The stream of saturated vapor with parameters as at point 20 is then divided into two substreams, having parameters as at points 11 and 12 respectively. Stream 11 passes through heat exchanger HE3, where it is partially condensed, releasing heat for process 3-8 (see above,) and obtains parameters as at point 14.

Meanwhile stream 12 enters into HE4, where it is where it is partially condensed, releasing heat for process 9-10 (see above,) and obtains parameters as at point 13. Streams 14 and 13 are then combined forming a stream of partially condensed working fluid with parameters as at point 21 corresponding to a state of vapor-liquid mixture.

Again, it is possible, in an alternate embodiment of the system, to utilize a single, dual flow heat exchanger in place of HE3 and HE4; in this case stream 20 is not divided, instead being sent in counterflow to both streams 9-10 and 3-8 in the dual flow heat exchanger, exiting with parameters as at point 21.

Stream 21 is then sent into a flash tank (gravity separator,) S1, where it is separated into a stream of saturated vapor with parameters as at point 22 and a stream of saturated liquid with parameters as at point 23. The concentration of the low boiling component *(ammonia)* at point 22 is slightly higher than the concentration of the low boiling component at point 1 (see above.)

Stream 23 is then divided into three substreams, having parameters as at points 24, 25 and 28 respectively. The stream with parameters as at point 28 is then sent into a pump, P3, where it is pumped to an increased pressure, and obtains as at point 29. Stream with 29 is then mixed with stream 19 to form stream 20, (see above.)

Stream 24 is meanwhile sent into a pump, P2, where its pressure is increased to a high pressure, and obtains parameters as at point 9, (see above.)

Meanwhile, stream 25 is mixed with the stream of vapor having parameters as at point 22, and forms a stream of basic solution with parameters as at point 26. The stream with parameters as at point 26 is then sent into HE2 where it is further condensed, providing heat for process 2-3, (see above,) and obtains parameters as at point 27.

Stream 27 is then sent into a heat exchanger (final condenser), HE1, where it is cooled and fully condensed by a stream of cooling medium (air or water) 51-52, (see below,) and obtains parameters as at point 1. The cycle is closed.

The cooling medium used for process 27-1, which has initial parameters as at point 50 is pumped to a higher pressure by a pump, P4, obtaining parameters as at point 51 before it is sent into HE1 as described above.

Note that the flow rate of the working fluid passing through turbine T1 is substantially higher than the flow rate of the working fluid passing through the condenser (HE1.) The flow rate passing through the turbine is equal to the sum of flow rates of the stream of basic solution passing through HE1 and the stream of lean recirculating solution (with parameters as at point 24) coming from the separator, (S1.)

The back pressure of the turbine, as well as the pressure of all of the returning streams of working fluid, are controlled by the required pressure for the condensation of the basic working solution in HE1. This pressure is usually quite high (in the range of 100-120psi.) The pressure at point 21 (entering into S1) is only slightly higher than the pressure in HE1. However, because the vapor produced in S1 (stream 22) must be at least slightly richer (having a higher concentration of the low-boiling component) than the basic working solution at point 1, this places a limit on the highest possible temperature at point 21.

At the same time, the temperature at point 3 (corresponding to the boiling point of the basic solution,) must be colder than the temperature at point 21. This limits the pressure at point 3. Thus, the pressure at point 17 (entering the turbine) is limited to a pressure at least slightly lower than the pressure at point 3. (The pressure at point 17 is usually in the range of 650-700psi.)

As a result, the turbine, T1, has a moderate inlet pressure and a substantial back pressure.

1.2 Analysis and Conclusions

System CS-21 uses a Kalex designed combustion subsystem called an RCSS (recirculation combustion subsystem.) The RCSS is a simple low cost subsystem developed by Kalex to allow the effective combustion and heat utilization of any type of direct-fired fuels, including (but not limited to) high wetness fuels such as biomass. By recirculating a controllable portion of flue gas back into the combustion chamber the RCSS is able to very precisely control the temperature of the combustion process, unlike conventional combustion systems. By maintaining the combustion temperature at just below the threshold at which NOx can form, an RCSS allows for the complete prevention of the formation of NOx, eliminating the need for NOx scrubbers.

System CS-21 uses a single, relatively low pressure turbine (with an inlet pressure of 650-690psi) with a high back pressure (of 110-120psi) This sort of turbine is much less expensive and more reliable than a turbine with high inlet pressure and vacuum stages, such as is used for conventional systems of this type.

Another advantage of the CS-21 system is that condensation occurs at a relatively high pressure. This reduces the volume of the working fluid in the condenser, increase the heat transfer coefficient (improving overall efficiency) and allows for smaller and less expensive condensers.

System CS-21 utilizes an HRVG (heat recovery vapor generator) with finned tubing as a boiler. An HRVG is much less expensive than a conventional boiler. The utilization of finned tubes in the HRVG, made possible by the use of the RCSS combustion subsystem mentioned above, allows the HRVG in system CS-21 to perform as well as or better than a conventional boiler. The use of the RCSS allows for the very precise temperature control required to make the use of an HRVG with finned tubing practicable with no danger of burning out the finned tubes. Although temperature differences in between flue gasses and the working fluid in the HRVG are substantially smaller than in a conventional boiler, this is more than compensated by the use of finned tubing, and the overall result is a drastic reduction in the cost of the boiler with no loss of overall efficiency for the system.

Overall, system CS-21 has a net thermal efficiency of approximately 37%; this allows for biomass power systems with efficiencies that are otherwise achievable only in very large base-load coal-fired conventional power plants. This represents an improvement of more than 40% over the efficiency of a conventional Rankine cycle biomass plant.

When comparing the efficiency of system CS-21 to the efficiency of large base-load conventional Rankine power systems, note that the base-load conventional Rankine power systems' overall thermal efficiencies are computed based on the use of large steam turbines with isentropic efficiencies in the range to 91% to 93%. Kalex CS-21 overall thermal efficiency is estimated based on the use small relatively inexpensive turbines with isentropic efficiencies of approximately 87%. Thus system CS-21's efficiency advantage can be achieved in spite of the use of smaller, less efficient (and less expensive) turbines.

In general, due to their higher efficiency, Kalex systems require the processing of less heat for a given output. As a result, the size of the combustion / boiler subsystem is drastically reduced, leading to substantial cost savings. Likewise the higher efficiency of these systems reduces the fuel used, leading to large savings in both the cost of fuel and the cost of fuel handling. The reduction in fuel use and costs in on the order of 30% or better. This savings also corresponds to a reduction of CO2 emissions for a given power output.

Overall, Kalex systems for biomass open up the possibility of using biomass fuels at efficiencies that are as high or higher than base-load coal-fired power plants and with per-kilowatt installation costs that are comparable to or lower than the per-kilowatt installation costs of base-load coal-fired power plants.

Figure 1
System CS-21