KALEX LLC.

Superior Efficiency
Reduced Costs
Viable Alternative Energy

Kalex
Kalina Cycle Power Systems
For Cement Kiln Waste Heat Applications

Kalex LLC's Kalina Cycle
for Cement Kiln Waste Heat Applications

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Kalex Systems for Cement Kiln Waste Heat Power.

Kalex has developed a power system and auxiliary technology that greatly improves the efficiency and reduces the cost of utilizing waste heat from cement kilns for power generation.

Industrial waste heat recovery represents a very diverse range of potential power applications, each with specific technical considerations and different characteristics of temperature and available heat. Waste heat recovery from cement kilns represents a large portion of currently available industrial waste heat sources.

A typical cement kiln has two sources of waste heat. Heat is available from the pre-heater and from the cooler. The heat source from the pre-heater is a flue gas with an initial temperature of approximately 340 deg. C., (644 deg. F.) This heat can be cooled to a minimum temperature of approximately 220 deg. C., (428 deg. F.,) which is the temperature at which the flue gas needs to be returned to the cement kiln installation.

The heat source from the cooler is hot air with an initial temperature of approximately 300 deg. C., (572 deg. F.) This can be cooled to a minimum temperature of 80 deg. C., (176 deg. F.,) which is the temperature at which the hot air needs to be returned to the cooler installation.

--Typical parameters of these heat sources are given in appendix A.

Cement kiln waste heat power systems encounter two major requirements which complicate their cost effective utilization.

The first is the technical difficulty in utilizing both sources of heat from a cement kiln in a single unified power system. This is caused by the differences in the initial, and especially in the final temperatures of the two hear sources. Thus, the efficacy of any power system utilizing heat from a cement kiln depends not only on the system's thermal efficiency, but also on the system's ability to utilize the maximum amount of heat from these two different heat sources.

Therefore, any power system utilizing heat from a cement kiln will have at least two parallel boilers, because the flue gas and the hot air cannot be mixed. This means that the working fluid of the power cycle must initially be heated by the hot air, then further heated by the hot air and the flue gas in parallel, and last by the flue gas only.

This means that a best case utilization of both heat sources would require the use of four separate heat exchangers; one for the initial pre-heating by the hot air (at maximum initial temperatures which are chosen to be equal to the lowest final temperatures of the flue gas,) then two more heat exchangers (boilers) working in parallel, in which the heat is supplied by flue gas and air (with an initial temperature of flue gas sent into the heat exchanger equal to the initial temperature of the hot air,) and finally by a fourth heat exchanger in which the flue gas is cooled from its initial temperature down to the initial temperature of the hot air. Such an arrangement, with four separate heat exchangers, results in excessive complexity and a high cost for the power system.

It is also possible to use two separate power systems, one to utilize the flue gas and one to utilize the hot air. However, this even more expensive and complex.

The second potential complication in the use of cement kiln waste heat is that Organic Rankine Cycles cannot be utilized, because the relatively high initial temperature of the heat sources would cause substantial decomposition of the organic working fluid. To use a Rankine cycle for such heat source, water has to be used as the working fluid.

Kalex LLC has developed system SMT-33 for the cost effective and efficient utilization of cement kiln waste heat. Unlike conventional powers systems that utilize cement kiln waste hear, SMT-33 uses only two parallel boilers.

The high efficiency of Kalex systems is based on the advantages of using a variable composition, multi-component working fluid. By separating and mixing the multi-component working fluid throughout the system, the characteristics of the working fluid at each point in the system can be controlled, greatly increasing the system's thermal efficiency without requiring exotic components, extreme temperature or extreme pressure. The use of a water-ammonia working fluid allows Kalex systems to operate with conventional components, steam turbines and heat exchanger apparatus. In fact, Kalex systems use only proven "off-the-shelf" components that are widely available in the power industry. By avoiding the use of experimental or specialized high cost components, Kalex systems can attain their high efficiency at low cost, while maximizing reliability and minimizing technological risk.

In particular, in SMT-33, the composition, and the initial temperature of the working fluid is designed to be different in each of the two parallel boilers, optimized to the different heat sources taken from the cement kiln.

--A detailed description of system SMT-33 is given in appendix B.
--A flow diagram of SMT-33 is given in figure 1.

When applied to heat sources outlined in appendix 1, SMT-33 attains a thermal efficiency of 27.43%, (*corresponding to a Second Law efficiency of 60.71%.*) It utilizes 52,683 thermal kW of heat source (89.5%) and delivers a net power output of 14,453 kW electrical.

For purposes of comparison, Kalex LLC has modeled a Rankine cycle optimized to the utilization of the same heat sources. Such a system attains a thermal efficiency of 23.56%, (corresponding to a Second Law efficiency of 48.85%.) It utilizes 41,523 thermal kW of heat source (70.6%) and delivers a net power output of 9,783 kW electrical.

Thus, the Kalex system delivers 147.7% of the output of an optimized Rankine cycle for the same heat source.

A general estimate of capital cost suggests that the Kalex SMT-33 system will have roughly the same overall capital cost as a Rankine system for the same application, however the higher output of the Kalex SMT-33 system as compared to the Rankine cycle system means that the cost per kilowatt of the Kalex system will be less than 70% of the cost of the Rankine cycle system.

A consideration in the use of cement-kiln waste heat is the fact that flue gas from a cement kiln usually contains a substantial quantity of cement dust. In the process of operation of a power system, this dust creates sedimentation on the surfaces of heat exchanger apparatus which results in the reduction of the heat transfer coefficient in the heat exchangers. Additionally, this dust causes a substantial amount of erosion of the tubes and fins inside the heat exchangers. It should be noted that the inlet pressure of the flue gas from a cement kiln into the power system is relatively low, which makes it difficult to separate this dust from the flue gas by conventional means, such as a cyclone dust separator.

To deal with this problem, Kalex utilizes two different solutions. One method is to install an expansion chamber in front of the heat exchanger. The velocity of the flue gas is drastically reduced in this expansion chamber, increasing the pressure of the flue gas. The reduction of the flue gas velocity allows the cement dust to precipitate out of the flue gas, substantially reducing the quantity of dust entering into the heat exchanger. At the same time, the increase of pressure of the flue gas increases the driving force of the flue gas through the heat exchanger. This allows for an increase in the velocity of the flue gas passing through the heat exchanger, resulting in a corresponding increase in the heat transfer coefficient of the heat exchanger.

--A description of the operation of an expansion chamber is given in appendix C.
--A diagram of an expansion chamber is given in figure 2.

Kalex LLC has developed another, proprietary solution to the problem of cement dust in the flue gas heat source. This subsystem is designated the Dust Removal Subsystem, or DRSS.

--A description of the operation of a DRSS is given in appendix D.
--A diagram of a DRSS is shown in figure 3.

The DRSS provides for effective dust removal from the flue gas heat source and also allows for a drastic reduction of the required heat transfer area in the heat exchanger where the heat from the flue gas is utilized. This delivers a substantial cost savings, in spite of the added cost of the DRSS.

In summary, Kalex's technology for utilization of cement kiln waste heat allows for cost effective and viable utilization of this heat source.

Appendix A:

Typical Parameters of a Cement Kiln Heat Source

Typical heat potential of a cement kiln waste heat plant consists of two heat sources:

--Preheater
--Cooler

Pre-heater:
Inlet Temperature: 340 degrees C.
Inlet Pressure: -5kPa
Gas Flow at above conditions: 900,000 cubic meters per hour
Gas Composition (by volume at operating conditions):

--Nitrogen	60%
--Carbon Dioxide	32%
--Water	5%
--Oxygen	3%

Minimum temperature to which gas can be cooled: 220 degrees C.

Cooler:
Inlet Temperature: 300 degrees C.
Inlet Pressure: -0.2kPa
Gas Flow at above conditions: 740,000 cubic meters per hour
Gas Composition: Air
Minimum temperature to which gas can be cooled: 80 degrees C.

Ambient Conditions:

Average Temperature:	20 degrees C
Maximum Temperature:	40 degrees C.
Minimum Temperature:	-5 degrees C.
Water Temperature:	20 degrees C.

Appendix B:

System SMT-33

System SMT-33 is designed to utilize two separate heat sources simultaneously. I.E, the system is designed to utilize a stream of flue-gas with a higher initial temperature and a stream of hot air with a lower initial temperature.

A conceptual flow diagram of system SMT-33 is given in **figure 1.**

The system operates as follows:

Fully condensed, basic working solution (rich solution --i.e., with a high concentration of low-boiling component, usually ammonia,) with parameters as at point 1, corresponding to a state of saturated liquid, enters into a feed pump, P1, where its pressure is increased, obtaining parameters as at point 2, corresponding to a state of a subcooled liquid.

Stream 2 now passes through a preheater, HE2, where it is heated in counterflow by a returning stream of condensing basic solution working fluid (26-27, see below) and obtains parameters as at point 3, corresponding to a state of saturated liquid.

Thereafter, stream 3 passes through a recuperative boiler-condenser, HE3, where it is heated and substantially vaporized in counterflow with a stream of condensing working fluid (19-21, see below,) and obtains parameters as at point 8, corresponding to a state of wet vapor (i.e., a liquid-vapor mixture.)

Stream 19-21 partially condenses in HE3, and, having parameters as at point 21, corresponding to a state of a liquid-vapor mixture, enters into a gravity separator, S1, where it is separated into a stream of saturated vapor, having parameters as at point 22, and a stream of saturated liquid, having parameters as at point 23.

The concentration of the light-boiling component (usually ammonia) in stream 22 is slightly higher than the concentration of the light-boiling component in the basic solution (see above.)

Stream 23 is now divided into three substreams, having parameters as at point 24, 25 and 28.

Stream 25 is now combined with stream 22 (see above,) forming a stream of basic (rich) solution with parameters as at point 26.

Stream 24 is now sent into a circulating pump, P2, where its pressure is increased to a pressure equal to the pressure at point 8 (see above,) and obtains parameters as at point 9, corresponding to a state of subcooled liquid.

Stream 8 is meanwhile divided into two substreams, with parameters as at points 10 and 30.

Stream 10 is now combined with stream 9, forming a stream of vapor-liquid mixture with parameters as at point 31. Due to the absorption of stream 10 by stream 9, the temperature at point 31 is increased, becoming higher than the temperature at point 10.

Meanwhile, stream 30 is sent into an evaporator, (HRVG,) HE7, where it is heated, fully vaporized and superheated, in counterflow with a stream of hot air (521-522,) obtaining parameters as at point 32.

At the same time, stream 31 is sent into an heat recovery vapor generator, (HRVG,) HE6, where it is heated, fully vaporized and superheated, by a stream of flue-gas (500-502, see below) and obtains parameters as at point 33.

Stream 33 now exits from HE6, and is combined with stream 32, forming a stream of working solution with parameters as at point 34, corresponding to a state of superheated vapor.

Stream 34 is now sent back into HE6, where it further superheated, obtaining parameters as at point 17.

Stream 17 is now sent into a turbine, T1, where it is expanded, producing work, and obtaining parameters as at point 18, corresponding to a state of superheated vapor.

Meanwhile, stream 28 (from S1) is sent into a circulating pump, P3, where its pressure is increased to a pressure equal to the pressure at point 18, obtaining parameters as at point 29, corresponding to a state of slightly subcooled liquid.

Stream 29 is now mixed with stream 18, forming a stream with parameters as at point 19.

The flow rate of stream 29 is chosen in such a way that it de-superheats stream 18, and that stream 19, (resulting from the mixture of stream 29 and 18,) corresponds to a state of saturated or slightly wet vapor.

Stream 19 is now sent into HE3 where it condenses, providing heat for process 3-8 and obtains parameters as at point 21 (see above.)

Meanwhile, stream 26, corresponding to a state of a liquid-vapor mixture, is sent into HE2, where it partially condenses, providing heat for process 2-3, and obtains parameters as at point 27, corresponding to a state of liquid-vapor mixture (see above.)

Thereafter, stream 27 is sent into the final condenser, HE1, where it is cooled and fully condensed by a stream coolant (50-51, air or water,) and obtains parameters as at point 1 (see above.)

The cycle is closed.

Stream 31 (see above,) has a temperature which is always lower than the lowest allowable temperature of the stream of flue-gas (at point 502.) Stream 30 has a temperature lower than the temperature at point 31. However, the temperature at point 30 is usually higher than the lowest allowable temperature of the stream of hot air (521-522.)

As a result, the heat potential of the flue-gas is fully utilized whereas the heat potential of the hot air is utilized to a very significant extent, though not fully.

Thus, overall, the, system SMT-33 attains a very high efficiency and a very high rate of heat utilization.

Appendix C:
Expansion Chamber for Dust Removal

An expansion chamber is an apparatus for the removal of solid particles from a stream of gas, in particular (but not limited to,) gas used as a heat source in a power system.

An example of this situation can be found in power systems based on the use of waste heat from cement plants, where the hot gas is heavily laden with abrasive cement dust. Another example can be had where the flue gas produced from the combustion of solid fuel carries a substantial quantity of solid particles such as ash or particles of un-combusted fuel.

These solid particles, if not removed, cause erosion of the heat transfer surface and sedimentation on the surface of heat exchanger apparatus, reducing the efficiency of heat transfer.

Removal of these particles by various sorts of filters cause substantial difficulties; such a filter would have to operate at very high temperature and in the case that a large amount of solid particles is high, the filter becomes clogged in a short time, causing substantial maintenance problems.

The use of cyclone separation apparatus is problematic in that it causes substantial losses of pressure in the stream of gas. Moreover, abrasive solid particles can cause substantial erosion in the cyclone apparatus itself.

The apparatus is shown in **figure 2** and operates as follows:

A stream of gas, laden with solid particles and moving at high speed enters into the inlet duct of the apparatus. Due to the high velocity of the gas the kinetic energy of the stream is high, which enables the stream to carry solid particles.

This stream then enters into an expanding duct. As the cross-section of the expanding duct increases, the velocity of the stream decreases and according to Bernoulli's Principle, the pressure of the stream increases.

The decrease in the velocity of the stream corresponds to a reduction of its kinetic energy (in proportion to the second power of velocity.) Therefore the ability of the stream to carry solid particles is drastically decreased.

Thereafter, the low velocity stream enters into a separation chamber where, due to the low velocity of the gas, the solid particles fall down into dust collector, located at the bottom of the separation chamber.

Due to the fact that the pressure in the collection chamber is elevated, the solid particles in the dust collector is easily removed through openings the bottom of the dust collector.

Thereafter, the gas from the separation chamber enters into a converging duct, where it's velocity increases and pressure decreases.

Thereafter, the stream of gas enters into an outlet duct and can be directed as needed.

An expansion chamber used for dust removal has the following advantages compared to conventional filters:

--It can separate a substantial quantity of solid particles without causing blockage of a filter.

--It can easily work with high temperature or low temperature gas without need for special high temperature filters.

--It has no moving parts and as a result is reliable.

Appendix D:
Dust Removal Subsystem for Cement Kiln Waste Heat Power Applications.

A substantial source of waste heat available for utilization in power production is waste heat from cement plants. This heat is available in the form streams of hot flue gasses and hot air.

However, a significant obstacle to the utilization of this heat source is the fact the gas and air carries a substantial quantity of abrasive dust. Because these sources usually have very small gage pressure (i.e., pressure above atmospheric pressure) it is impossible to install effective filters to separate this dust directly from the gaseous stream.

If these heat source are not cleaned of dust, the dust will cause substantial erosion of the surfaces of heat exchangers and diminishes the efficiency of heat transfer as a result of the dust being deposited as sedimentation on the heat transfer surfaces.

Kalex LLC has developed a process and apparatus, designated a "Dust Removal Subsystem," or "DRSS," for separating dust from gaseous waste heat sources and providing effective heat transfer to the working fluid of a power cycle that utilizes such waste heat.

A diagram of a DRSS is presented in **figure 3**.

The DRSS is comprised of a centripetal separator ("cyclone") "C," a scrubber, "S," recirculating pump for high temperature heat transfer fluid, "P," a filter "F," and a heat exchanger, "HE," in which heat is transferred to the working fluid of a power cycle.

The DRSS operates as follows;
A stream of hot gasses, with parameters as at point 1, passes through cyclone C, where large particles of dust are separated from the stream by centripetal forces, obtaining parameters as at point 2. One experienced in the art can easily select a proper type and design of cyclone C for this purpose.

Thereafter, the stream of gas, 2, still carrying a substantial quantity of dust, is sent into the bottom of a scrubber, S. Simultaneously, at the top of scrubber S, a stream of high temperature heat transfer fluid, with parameters as at point 4, is sent into the scrubber. In the preferred embodiment of the DRSS, the packing in the scrubber is made of a sheet of corrugated material (metal or other material suitable to high temperatures) layered with a sheet of non corrugated material, and then formed into a roll. However other types of scrubbers can be used as well, including scrubbers with combinations of different sorts of packing.

Such a packing forms multiple vertical channels through which the heat transfer fluid flows down as a film on the surface of these vertical channels. At the same time, the dust laden gas flows up the center of these vertical channels.

In this process the gas is cooled and the high temperature heat transfer fluid is heated. Particles of dust cannot contact the surface of the packing material directly, but rather contact the surface of the film of down-flowing heat transfer fluid. Since the density of the liquid is many times higher than the density of the gas, the particles of dust that penetrate through the down-flowing film of liquid lose their kinetic energy and thus cannot cause damaging erosion of the packing material of the scrubber. In general, one experienced in the art can choose and/or design an appropriate type of scrubber for this purpose.

Thereafter, the high temperature heat transfer fluid, which has been heated by the gas, and is carrying the dust that was brought in to the scrubber by the gas (steam 2,) leaves the scrubber with parameters as at point 5. Meanwhile, the cooled gas leaves the scrubber with parameters as at point 3.

Thereafter, the fluid (stream 5) enters into a pump, P, where it's pressure is increased, and obtains parameters as at point 6. Thereafter the fluid (stream 6) passes through a filter, F, where dust is separated from the fluid which then obtains parameters as at point 7. The most suitable filters for this purpose as knitted mesh filters which can operated at very high temperatures.

To maintain constant operation, two filters can be installed in parallel, of which one is in operation and the other is standing by. When one filter becomes overly filled by dust, operation switches to the other filter, while the first filter is cleaned and then retuned to use.

Stream 7, which consists of heated high temperature heat transfer fluid which has been effectively cleaned of dust, is then sent into the heat exchanger, HE, where it moves in counterflow with a stream of working fluid from the power cycle, 8-9. Here the heat from the high temperature heat transfer fluid is transferred to the working fluid of the power cycle.

Thereafter, the now cooled high heat transfer fluid exits the heat exchanger, HE, and obtains parameters as at point 4 prior to being sent into the scrubber, S, (see above,) thus completing the system.

It should be noted that a similar effect could be had by increasing the pressure of the initial dust laden gas and running it through a filter. However, such a compressor would use a great deal of power and would be subject to heavy erosion.

The DRSS not only prevents erosion of heat transfer equipment due to dust, but also provides a substantial increase the efficiency of heat transfer from the heat source to the power cycle. Heat transfer in the scrubber, S, which is in essence a direct contact heat exchanger, is extremely efficient. Heat transfer in the heat exchanger, HE, because it is performed by a fluid of much higher density than gas, is also many times more efficient that would be the case if the heat transfer was performed directly from the heat source gas to the working fluid of the power cycle.

An additional advantage of a DRSS is the ability to operate without interruptions to clean the surfaces of heat transfer apparatus from dust, which in turn provides for higher availability and reliability of a power system utilizing the DRSS.

Figure 1:
SMT-33

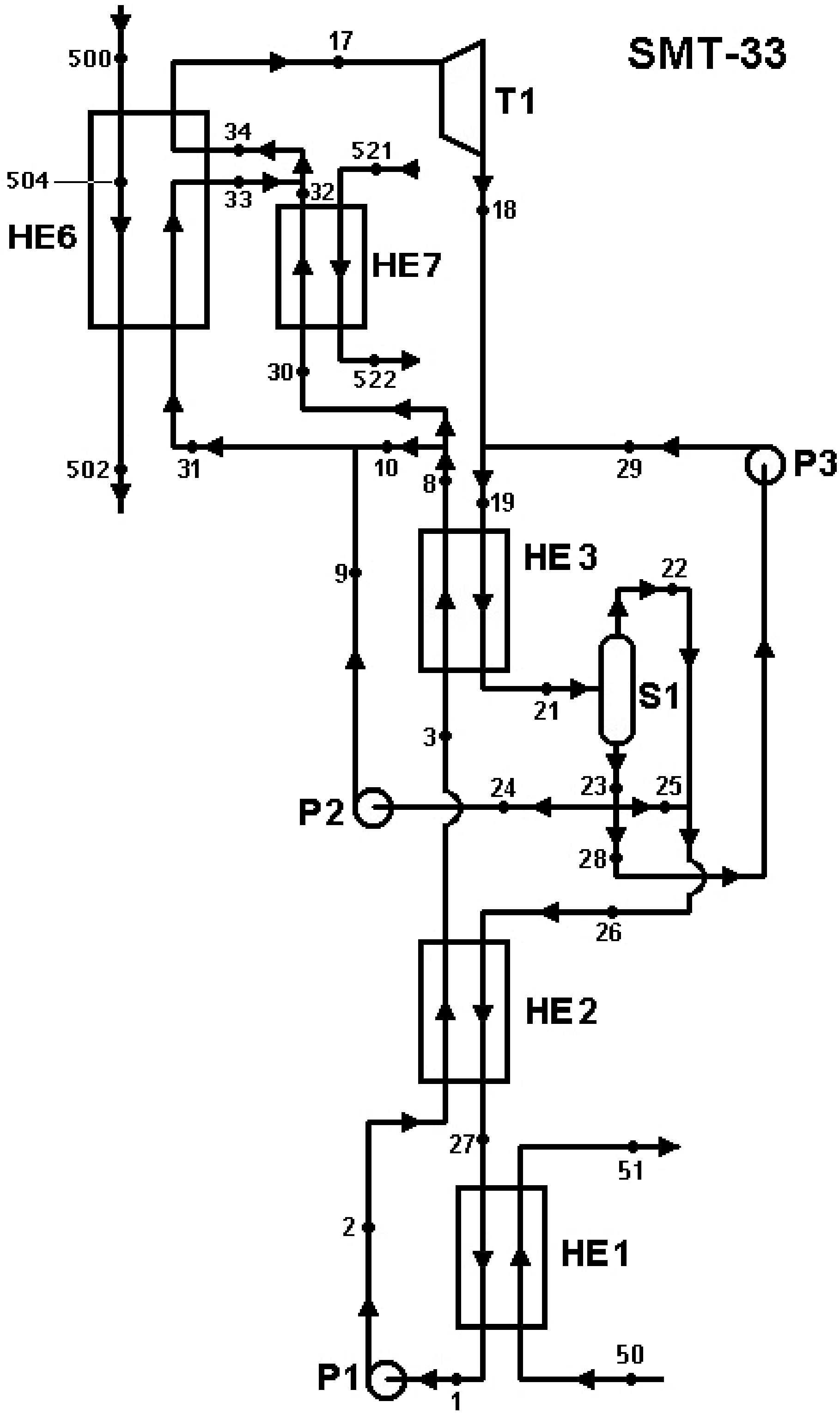

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Figure 2:
Expansion Chamber for Dust Removal from a Cement Kiln Waste Heat Power Plant

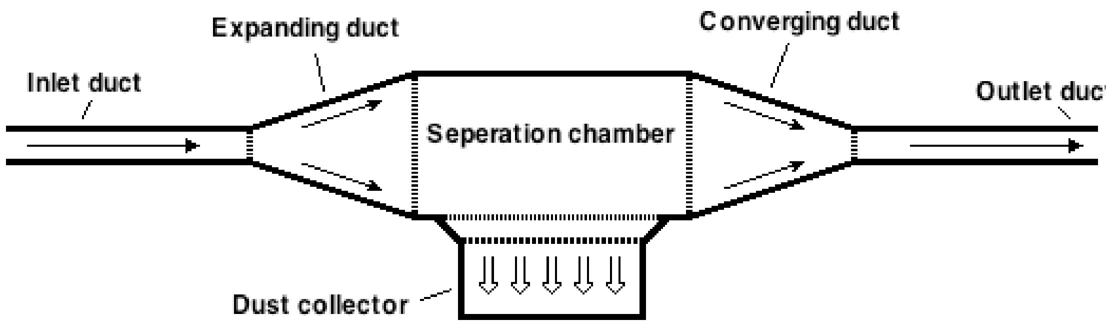

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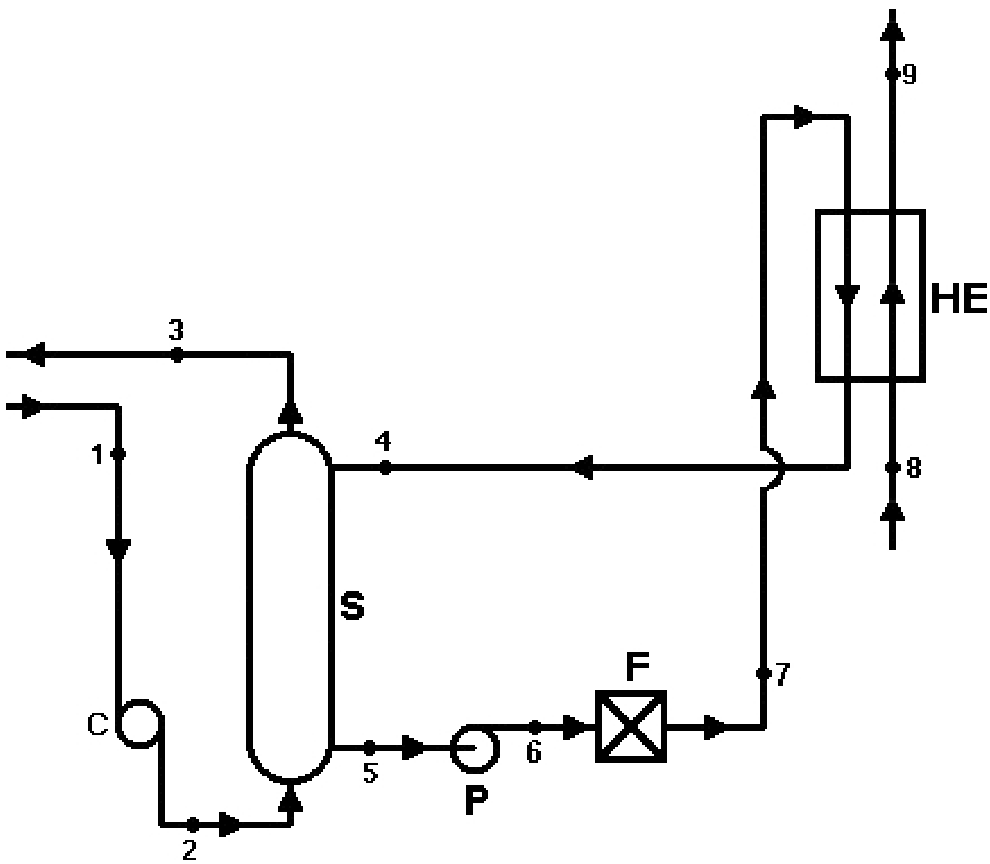
Figure 3:
Dust Removal Subsystem; (DRSS)



For further information, please see Kalex LLC's website at **www.kalexsystems.com**
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