Packaged Solid Fuel Based Energy Production & Water Purification System

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Abstract:

It is estimated that 1.2 billion people worldwide lack safe water for consumption. At least 2 million people, most of which are children, die each year as a result of water borne diseases. It is also estimated that 1.6 to 2 billion people worldwide live without electricity. Even before fossil fuel prices skyrocketed in the world markets, the possibility of building infrastructure for these regions using conventional approaches that rely on fossil fuels was economically difficult, if not impossible. This is often not viable from a practical standpoint because many areas lack infrastructure for fuel delivery; whether by rail, pipeline or other transportation means. Adding fossil fuel based generation to these areas is generally infeasible as a result of extremely high costs and the lack of infrastructure. Further, building infrastructure for third world or developing regions that is based upon fossil fuels will increase the already strained demand on world energy markets while adding to greenhouse gas emissions.

To address these needs, this paper will present the economic and technical viability of a packaged solid fuel based system for generating renewable energy, purified water and fertilizer additives. The core technology of the system will be the patented Aireal® Combustion System ("ACS"). The system will address a principal need for an economical and technically viable source of electricity and purified water that is essential for communities in undeveloped regions in the world.

An economical system is needed for energy generation in underdeveloped regions that can use available renewable energy sources. Small scale, solid fuel based systems have been demonstrated to be technically viable while meeting the newest and most stringent environmental regulations. One of the newest technologies that has been successfully used in solid fuel combustion is the patented Aireal® Combustion System. The ACS coupled with a heat recovery steam generator ("HRSG") and air pollution control ("APC") equipment has been shown to be economically and technically viable in small scale applications. This system is capable of efficiently combusting a wide variety of biomass feed stocks that are readily available in many regions, including waste wood, bagasse, coconut hulls, rice hulls and grasses to produce thermal energy, which will be converted from a gaseous thermal source to steam in the HRSG. The steam will be used to produce electricity in a simple backpressure turbine. The turbine exhaust will be used to produce distilled water which will have essential mineral additives such as potassium and sodium. The HRSG exhaust will be cleaned using modern APC equipment such as a fabric filter. Using renewable resources, the system will produce electricity for industry and residential. The system will also produce purified water and ash residue for fertilizer.

The recommended system size, specifications, configuration and outputs will be discussed. In addition, several key elements of the system will be presented:

1. Utilizing a standard design and components to eliminate the engineering costs that are associated with custom designs for each application
2. Utilizing a packaged system design consisting of modules and skid mounted equipment to reduce costs and maintain consistent quality of product
3. Utilizing state-of-the-art technology for combustion, energy recovery and control of hazardous air pollutants
4. Availability of renewable resources for sustained economic viability
5. Necessary, training for operations and maintenance; availability of spare parts; and maintenance support
6. Utilization of every system output by the economic community

Based upon these qualifications, it is expected that the Aireal® Combustion System has strong potential to profoundly impact the capability of developing communities to sustainably deliver both power and clean water for the betterment of social and economic conditions.

Introduction

It is virtually impossible for impoverished communities in under-developed or developing regions to emerge from poverty in today's global economy without certain critical elements of infrastructure including:

- ✓ Affordable energy to support residential, health, education and manufacturing needs
- ✓ Clean water at an affordable price for households, industry and public facilities
- ✓ Sanitary waste treatment for both household and public facilities
- ✓ Delivery systems for energy, water and sanitary waste treatment
- ✓ Sustainable agriculture to support the nutritional needs of the community and optimally for export
- ✓ Manufacturing to provide jobs and support a local economy that is self sustaining

There are many constraints and impediments to implementation of equipment and facilities that provide for these essential needs, the largest of which is usually affordability. Centralized energy and water production are generally far more efficient and economical than micro-sized systems. In addition, financing centralized systems is often easier to accomplish in a way that provides for the essential needs of the entire community rather than financing at a user level, which often results in only the relative affluent sector having more modern facilities.

The focus of this effort was to evaluate the technical and economic feasibility of using state-of-the-art technology for small scale centralized systems to generate electricity, purified drinking water and process steam where needed for manufacturing and production. The following criteria were chosen for the reasons noted amongst the myriad of options potentially available to complete the evaluation:

1. Biomass was selected as the energy source rather than wind, solar or fossil fuels. This selection was based upon the widespread availability of various biomass fuel sources including waste wood and waste agricultural materials. Biomass fuels can be a consistent and reliable fuel source that is competitive with alternatives on a delivered cost basis. The low cost of local labor for processing in the targeted locations for a facility such as this is expected to help with reducing the delivered fuel cost of biomass fuels. Additionally, combustion of biomass fuels has a net zero carbon footprint in terms of Greenhouse Gas (GHG) emissions.
2. A basic Rankine cycle was selected with certain design options evaluated as discussed herein.
3. The Aireal© Combustion System (ACS) was chosen as combustion technology based upon its unique design features that include:
    a. Simplicity of design
    b. No moving parts in the furnace
    c. Low installed cost
    d. Low operating costs
    e. High operating availability
    f. High combustion efficiency
    g. Commercial facilities operating with small unit sizes as will be needed in many of the applications for impoverished communities
    h. Access to performance and cost data necessary to complete the evaluation
    i. Ability to control the costs of production for these applications
4. A standard unit size combusting 150 tons/day of biomass fuel was evaluated This system size was selected based upon the following:
    a. Economies of scale
    b. Greater life impact for large numbers of people
    c. System pricing availability
    d. Ability to control emissions to current standards for industrialized nations
5. The biomass fuel stream was assumed to be a mixture of biomass waste types that will likely be available in regions that can potentially support a facility such as that discussed herein. Those feedstocks may include coconut waste components (principally hulls and palm leaves) based upon other research that indicates that coconuts are a rich food source that can be utilized in the tropics and sub-tropics. Other bioimass feedstocks can also include waste wood from trimmings, rice hulls, getropha hulls and other types of agricultural waste components. Biomass feedstock may also be specifically grown for energy generation from fast growing hybrid sources such as poplars and switchgrass. A composite design higher heating value (HHV):of 5,930 btu/lb was determined based upon the following ultimate analysis:

Component	**% by Wt.**
Carbon	37.2%
Hydrogen	4.2%
Oxygen	27.0%
Ash	1.4%
Moisture	30.2%
	100.0%

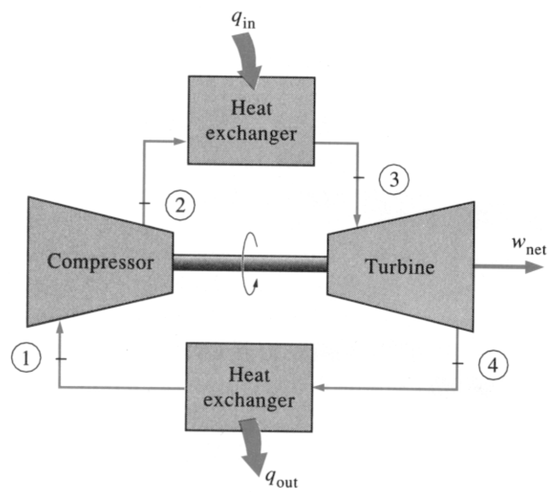
Related Work:

Much work has been done in the area of both purified drinking water and energy for small scale applications in poverty stricken regions of the world. Water for People and World Vision for example have both implemented a variety of technologies to provide both water and purified water for impoverished communities. Most of the technologies employed however are extremely simple and often do not provide water purities consistent with standards required in developed nations. A multitude of large scale water treatment systems are available for deployment including conventional sand filter / flocculent / hypochlorinating systems as well are reverse osmosis filtration systems. Both require power for operation despite their relatively simplistic design and have limitations such as the need for liquefied chlorine which is extremely hazardous to ship, store and handle. It can also be difficult to ship to remote regions.

Similarly, several small scale power systems have been developed for urban applications in undeveloped regions of the world. Conventional systems are reciprocating engine driven generator sets fueled by either diesel or natural gas in most cases. However, while highly efficient, they are dependent upon fossil fuels which are very expensive, contribute to GHG emissions. In recent years, there has been advancement in technologies that gasify biomass fuels to produce a synthetic gas that can also be combusted in both reciprocating engines and combustion turbines. Very few of these technologies have actually been commercialized and most continue in the development phase at a pilot project level. At least two however have been commercialized thus far. Furthermore, research and advancement in the development of biodiesel fuels that has been done for use with conventional reciprocating engines and combustion turbines. Production, refining and transportation costs have thus far limited the commercial application of this biofuel technology on a large scale basis. The two principal feedstocks targeted for biodiesel production are palm oil and getropha oil. Even though the soils and geography may be suitable to grow the feedstocks for biodiesel in impoverished regions, the transportation to and from the refinery may make this alternative economically infeasible in many cases.

Other types of biomass gasification systems are in development that use alternate approaches such as the Brayton cycle. With this approach, high pressure air is heated from the combustion of synthetic gas generated from gasification of biomass. The high pressure, heated air is then released in a turbine with a generator for electric generation. However, the efficiency of this cycle thus far is very low, typically in the 5-10% range. This is probably a primary reason that the technology is yet to be fully commercialized. A diagrammatic overview of this type of brayton cycle approach is shown in Figure 1 below:

Figure 1 – Brayton Cycle with Synthetic Biogas



The most advanced to date of the biomass gasification based power generating systems appear to be micro sized units in the 25 KW to 50 KW range. These systems do not use a Brayton cycle, but rather gasifiers that fuel conventional reciprocating engine generator sets. The small size of these systems is a severe limitation in terms of their relatively low electrical output. In order to have a large scale impact, a very large number of the packages will be required for many communities. More importantly the capital cost for these systems appears to be very high on a $/KW basis when compared to other conventional direct combustion alternatives. In addition, the overall cycle efficiency of these systems appears to be less than conventional Rankine cycle systems. Further complicating the application of gasification systems developed to date is the very restrictive fuel specification that includes extremely low moisture content, limited percentage of fine particles and a relatively small particle size of fuel. These systems certainly are state-of-the-art and offer tremendous potential, but may not be cost effective on a wide-scale basis.

Planned System Overview:

A cross section of the boiler and power generation system is shown in Figure 2 below. The ACS technology does not require pre-drying of the biomass feedstock and can accommodate a wide variety of biomass feedstock including waste wood, coconut hulls, trimmings and agricultural residues. Particle sizing is not a significant issue with the system and thus materials as large as 12" – 24" in one dimension can be accommodated. Fuel grinding will be performed with a tub grinder or chipper depending upon the application. Power for the fuel grinder and all other plant process equipment will be from the plant generator except during startup. During startup, a standby diesel generator will be used for operation of motors and other electrical equipment until the system reaches a self sustaining level.

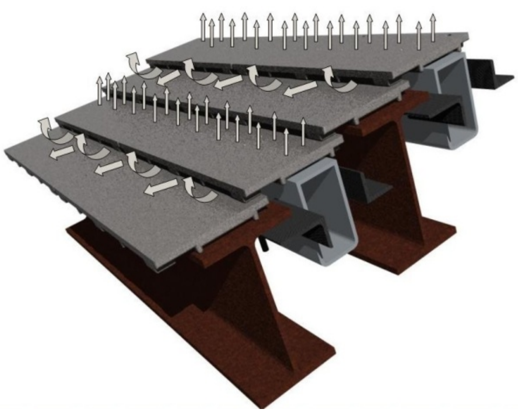
Figure 2 – Combustion Boiler System Overview

1.Fuel Storage Hopper
2.Metering Feeders
3.AIREAL® Combustion System
4.Combustion Chamber
5. Ash Discharge System
6. Boiler/Superheater System
7. Economizer
8. Fly Ash Handling System
9. Multiclone
10. Fabric Filter
11. Induced Draft Fan
12. Stack

Fuel will either be stored in a fuel storage building if the annual precipitation is high or in outdoor piles for arid climates. Fuel will be fed to the combustion unit fuel storage bin via an in-feed conveyor with level detectors. The fuel storage bin will be sized for several hours of operating capacity with a tapered bottom where rotating screw feeders will automatically feed material to the ACS grate assembly.

The Aireal® Combustion System was developed as an alternative to existing combustion technologies that required moving parts in the combustion zone. The Aireal® technology uses a sloped grate and pulse air to migrate the fuel down the surface of the grate and through the combustion chamber with no internal moving parts. Combustion air is principally provided through overlaps in the surface of the grate. Pulsing action through holes in the grate provides the necessary agitation to ensure optimum burn out and very low levels of unburned carbon in the fuel. Flue gas re-circulation (FGR) is used to control flame temperature in the furnace. Fuel is combusted as it migrates along the inclined “grate” surface, which is segregated into three zones: drying, volatilization and completion. In the drying zone, moisture in the fuel is evaporated to allow for efficient combustion. The volatilizing zone provides for conversion of hydrogen from the fuel to water and carbon in the fuel to carbon dioxide. The completion zone provides for final volatilization of the remaining carbon in the fuel as well as cooling of the ash residue. The ash residue is discharged to an ash storage hopper and conveying system which transports the ash to an external silo for mixing with soil as a fertilizer additive. Ash collected from other points in the system including the fabric filter, multi-clone and boiler hoppers is also transported via screw conveyor to the ash storage hopper.

Air for combustion is introduced in three ways; “underfire air”, “overfire air” and pulse air (including purge air). Underfire air is introduced through the fuel bed in a controlled manner to support drying, volatilization and completion. Underfire air is introduced through several undergrate plenums which provide for proper distribution and proportion of undergrate air. Overfire air is introduced above the fuel bed at multiple points in a highly turbulent fashion A smaller portion of the combustion air is introduced through the pulsing system; a portion of which is continuously injected as “purge air”). Underfire, overfire and pulse air are controlled automatically by the combustion control system. The following diagram illustrates the process of the pulsing action as well as introduction of underfire air:



Fuel is agitated as it migrates along the grate surface via a high pressure air distribution system that is separate from combustion air. This “pulse system” provides periodic bursts of high pressure air through the fuel bed across the furnace width at multiple points along the inclined grate surface. Pulse air assists with migration of the fuel during combustion and for agitation of the fuel for efficient combustion. Pulse air is introduced through small holes in the grate surface. The pulses are automatically controlled by the combustion control system. Pulse action is typically less than 1 second in duration. The upper zone of the grate is pulsed more frequently than the lower zones. A small portion of air is allowed to pass through the pulse holes on a continuous basis for cooling and cleaning purposes. Pulsing provides for the following:

1. Fuel agitation
2. Fuel drying
3. Fuel volatilization through suspension firing
4. Assistance with fuel bed migration
5. Combustion temperature control
6. Grate cooling

Another key feature of the Aireal™ Combustion System is the utilization of the pulse gas system in combination with recycled flue gas throughout the combustion process for temperature control during combustion. Cool recycled exhaust gas is returned from the discharge of the air pollution control system and injected throughout the combustion process. Re-circulated flue gas (FGR) is used to control temperature in the combustion process, minimize the formation of “clinkers” and to minimize the formation of nitrogen oxides NOx.

Combustion will occur in a waterwall style boiler designed to convert the thermal energy from combustion of the biomass fuel to thermal energy in the form of steam. The boiler will be configured with several sections to optimize energy recovery while minimizing the formation of slag buildup on the tube surfaces. These sections will include:

- Waterwalls - form the outer casing of the combustion zone where hot water is circulating and changing state to steam.
- Superheater –thermal heat is added to the saturated steam to form superheated steam necessary for improving cycle efficiency.
- Generating Banks – hot water begins a phase change in these tube sections.

- Steam Drum – This horizontal high pressure vessel is where saturated steam is flashed with the wet steam being discharged to the superheater and any condensed water circulated back to the lower generating bank for further heating.
- Economizer – Hot boiler feedwater supplied from the feedwater heating section of the deaerator is heated with the coolest gases in the boiler. The gases exiting the economizer have no further thermal use except with the water treatment system.

The cool gases exiting the economizer enter the air pollution control (APC) system. Biomass combustion fortunately does not contain many hazardous pollutants. Therefore, a simple APC system is all that is required to meet even the most current environmental standards for industrialized nations. A multi-clone will be the first step in the APC gas path where large particles and any embers that have been carried through the boiler will be removed. The gases will then enter a fabric filter where fine particles will be removed. The fabric filter will be a single compartment with an automatic air pulsing system for bag cleaning. Ash deposited in the collection hoppers beneath the fabric filter, multi-clone and boiler will be conveyed to the central ash collection hopper at the combustion system discharge point via screw conveyors.

Three fans will be used to support the overall process. An induced draft fan will draw combustion gases from the furnace and discharge to the stack while maintaining a negative pressure throughout the gas path. A combustion air fan will provide positive pressure on a controlled basis as underfire air through the grate and overfire air above the grate in the furnace. A flue gas recirculation fan will draw clean combustion gases from the stack for injection in the combustion zone for control of NOx, combustion temperatures and slag formation. Clean combustion gases will be discharged to the atmosphere via a discharge stack. A continuous emissions monitoring system will be used to monitor carbon monoxide, oxygen and opacity in accordance with current environmental regulations.

Superheated steam generated in the boiler superheater will be delivered to a steam turbine generator where the thermal energy will be converted to mechanical energy in the steam turbine which in turn will convert the mechanical energy to electrical energy in the generator. The turbine will be a multi-stage design which will either be a condensing machine or backpressure machine depending upon the water treatment system that is utilized.

For all cases analyzed a design steam pressure of 900 psig and design temperature of 800 ^{O}F for the turbine inlet steam was used. This pressure and temperature was selected based upon an industry standard for biomass fuels.

An air cooled condenser was selected for the condensing means on the turbine exhaust for all cases analyzed. This selection was based upon a design condition that minimized the need for significant quantities of cooling water for alternatives such as evaporative cooling towers. The size of the air cooled condenser must be designed with surface areas based upon the type of water treatment system that is utilized. Where a condensing turbine is used for electric based water treatment systems, the air cooled condenser surface area is expected to be larger than for a backpressure machine utilizing distillation to aid in the condensing of the turbine exhaust steam.

Multiple design configurations were evaluated to determine the optimum configuration for generating electricity and purified water using available biomass feedstock. Several water treatment systems were evaluated to determine the optimum configuration that maximizes efficiency, electrical production and purified water generation. The systems evaluated were:

- Steam Based Multistage Flash Distillation
- Multi Effect Distillation
- Electric Based Multistage Flash Distillation
- Reverse Osmosis (RO)
- Electric Based Mechanical Vapor Compression (MVC) Distillation
- Conventional Municipal Treatment:
    - Sand Filtration
    - Clarifiers
    - Chlorination

The results of the analysis, conclusions and recommendations are discussed in the corresponding sections below.

System Packaging:

In most applications, the ambient conditions are such that the systems will be located in tropic or subtropical climates. Therefore, freeze protection is not required. The equipment design is expected to be for outdoor service. Key equipment with heated internals such as the combustion system, boiler, hot gas ductwork, APC system components, steam piping and hot water piping will be insulated with embossed aluminum lagging for moisture and physical protection. The turbine generator, control room, switchgear, maintenance facilities, storage, key instrumentation and the CEM's will be located in enclosures that are weatherproof. Standard ISO shipping containers may be customized for the bulk of these needs on a standardized basis.

The overall facility design is anticipated to be such that it can be standardized, shop fabricated and packaged or skid mounted to the maximum extent possible. This offers tremendous cost advantages while reducing risks associated with construction and startup of sophisticated equipment as is contemplated herein. It also dramatically reduces the need for skilled craft labor at each of the sites where the systems will be installed. In addition, standard foundations will be designed that will conservatively accommodate most subsurface and geologic conditions. In all likelihood, this will involve pile type foundations in lieu of spread footers or other designs. Key equipment for construction including cranes, pile drivers, welders, rigging and tools will be shipped to each site for use during construction and then shipped back to a central location until it is needed on subsequent installations. This will be an essential element to ensure all necessary equipment, materials and tools are shipped with the equipment to facilitate installation and startup. Electricity needed for construction will be via a standby diesel generator that will be a part of the overall facility design. This unit will be one of the first items installed.

It is anticipated that the entire facility as well as all necessary construction equipment, supplies, consumables and tools will be packaged for shipment on a single cargo ship to then be docked at the nearest port for unloading and transportation to the site via truck facilities. This may require that ground transportation equipment accompany the facility equipment to ensure properly designed transportation trucks and trailers are available. The transportation equipment will in that case be returned with construction equipment once the facility construction and startup is completed.

Operating and maintenance staff will be trained by a team of engineers and technicians who also complete the startup and checkout of the facility as construction is completed. To the maximum extent possible, the system will be checked out prior to shipment, including instrument calibration to minimize the amount of work required for startup of the facility.

Performance Modeling Results:

In order to accurately complete performance modeling of the various scenarios, heat and mass balance modeling was performed using GatesCycle software. Two basic scenarios were run to first determine whether steam based distillation systems would be more efficient than electric based systems and to evaluate overall system performance outputs. These two options were:

1. Steam based distillation for water treatment with the process steam for distillation supplied by a backpressure turbine
2. Electric based water treatment systems with a full condensing turbine to maximize electrical output

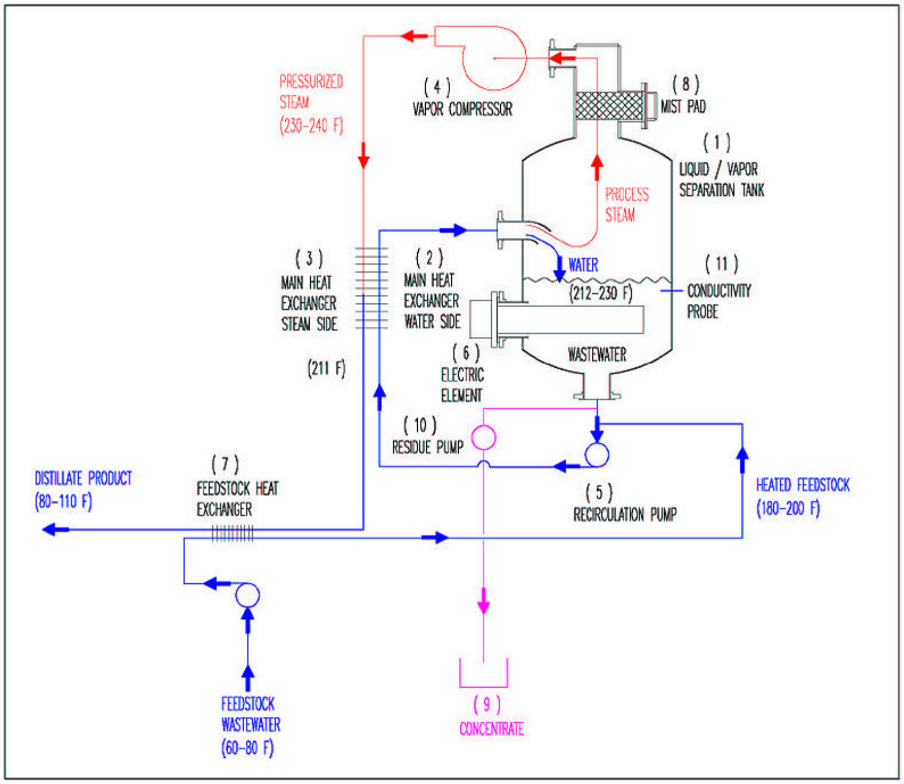
Diagrammatic overviews of these heat and mass balance scenarios are provided in Appendix A. As indicated with the heat and mass balances, the outputs of the two configurations vary substantially. The backpressure turbine configuration with steam distillation yielded a gross electrical output of 3,424 KW and 43,000 pounds per hour, or 123,840 gallons per day (GPD) of purified water. The amount of water produced is extremely high for a likely target sized community. Assuming 1 gallon of purified water per day for human consumption, the water production is sufficient for roughly 124,000 people.

In comparison, the condensing turbine model without the distillation system yielded a gross electrical output of 4,672 KW with no water production. The cost of water production in terms of reduced electrical output was 1,248 KW; roughly 27% of the total output potential. It must be noted that with either configuration, the plant electrical (parasitic) load must be accounted for. Excluding electrical needs for external water purification systems, the parasitic load was estimated at approximately 700 KW. Therefore, the net electrical output for the backpressure turbine configuration with steam distillation yielded a net electrical output of 2,724 KW. Similarly, the condensing turbine without the distillation system yielded a net electrical output of 3,972 KW with no water production.

It is difficult to determine the ultimate average electrical consumption per home for an emerging community that would have reasonably priced electricity available. Assuming an average household demand of 250 watts for lighting and cooking and 4 people per household, the net electrical production of 2,724 KW from the backpressure turbine configuration with steam distillation would support approximately 40,000 people. This would suggest that the steam based distillation approach would probably yield a likely imbalance between the amount of purified water and electricity produced on a per capita basis (120,000 people verses 40,000 people). If a percentage of the electrical output is utilized for industrial purposes such as agricultural processing, the number of people that the electric output would support becomes even more disproportionate. For example, if 1,000 KW is used for non-household requirements, the net available power is reduced to 1,724 KW. Using the same assumptions for per capita electrical consumption, the number of people that this configuration would support is reduced to roughly 7,000 people. It should be noted that this analysis does not account for “peak” verses “off-peak” electrical demand fluctuations.

Given the above comparative analysis, a better configuration was determined to be the full condensing turbine without steam based distillation and utilizing an alternate electric based water purification system for most applications. A comparison of various other purification options indicated that electric based mechanical vapor compression (MVC) distillation would be a good technology to couple with a full condensing unit if that option were chosen to maximize power output. Summary level manufacturer’s information is included in Appendix B for this type of purification system. A diagrammatic overview of the MVC process is shown in Figure 3 below:

Figure 3 – MVC Process



The principal factors that led to the above conclusion were:

- System cost
- System efficiency (KW per 1,000 gallons of water production)
- Portability
- Quantity of waste water effluent

Reverse Osmosis for example has a tremendous amount of waste water effluent, which increases with higher amounts of dissolved solids and suspended solids in the raw water supply. Given that likely raw water sources will include high dissolved and suspended solids, RO is probably not a good option for the targeted application with this facility. Regardless of the water treatment system utilized, pretreatment with a backwashing pre-filter or strainer will be needed in most applications. The MVC water purification system coupled with the condensing turbine electric generation configuration is discussed further in the Conclusions and Recommendations.

It should be noted that with any distillation based water purification process, minerals may need to be added to the water prior to human consumption. This is a fairly nominal cost, but may be essential for human health. It is also worth noting that the quality of purified water to be generated with the water purification options analyzed with this evaluation are all at or above the quality of most bottle water brands currently sold in the market; whether in industrialized nations or developing regions.

Projected System Costs:

A preliminary cost estimate was developed for the condensing system case, given it was determined to provide the highest electrical output and increased flexibility as will be discussed further in Conclusions and Recommendations. The total installed facility cost was estimated at $16.6 million based upon the assumptions noted below. This cost projection includes a backup diesel generating system with equivalent electrical output to the steam turbine generator. The backup diesel generator will be used during periods the biomass based system is off-line to maintain electric generation to the community on a 24 hour per day, 365 day per year basis.

A few of the key assumptions used in the facility cost projection are as follows:

- Standardized designs will allow for the facility design costs to be spread across multiple units
- Fabrication of components will be completed in lower cost regions of the world to reduce costs
- Equipment manufacturers will provide pricing discounts of 10% - 20% for volume and application in poverty stricken communities to improve living conditions for humanitarian purposes

The above cost estimate excludes the MVC water purification with mineral additive system. The costs for MVC distillation systems obviously vary by size. The estimated installed capital cost for a 1,800 GPD system including mineral additive features is $1 million.

Conclusions and Recommendations:

Based upon the performance and cost modeling performed, it was determined that a condensing turbine which maximizes electric output was likely to be optimum for most applications. A portion of the electric output should be used with MVC based distillation to provide purified drinking water. This configuration was determined to provide the highest electrical output with equivalent purified water production among the various options analyzed. In addition, it enables greater flexibility in terms of varying water production with electrical output depending upon the needs of a given community. For example, multiple MVC type water purification systems could be located within a community to minimize water distribution costs.

The following financial proformas were developed to determine the costs for electric and water production based upon the results of the performance analysis completed:

1. 150 TPD biomass facility with condensing turbine for electric generation without water purification
2. 150 TPD biomass facility with condensing turbine for electric generation with 1800 GPD water purification using MVC

This financial analysis was first necessary to determine the costs for electrical production with the system configuration using biomass fuels. In addition, it enabled a determination of the cost for purified water per gallon assuming the same wholesale electric sales rate and facility economics. The proforma financial analyses indicated a wholesale electric sales rate of $0.155/KW-hr is necessary for the recommended facility to be economically feasible. In addition, a wholesale water sales rate of $0.03/gal will be required to maintain the facility economics with a $0.155/KW-hr electric rate and 180 KW being used to generate the 1,800 GPD of purified water. These rates are certainly within current market rates for both energy and purified water. It is important to note that the projected rates include the capital and operating costs for a backup diesel generating system that will provide equivalent electric production during periods where the biomass based generating system is off-line.

The following key assumptions were used in the proforma economic projections:

- No differentiation was made between "peak" and "off-peak" sales rates.
- Operating labor rates will be much lower than in the US or other developed countries.
- Biomass fuel costs are lower than in the US or other developed countries due to the lower cost labor available for gathering feedstock and operating processing equipment. A delivered biomass fuel cost of $15/ton was used.
- Biomass fuel consumption of 46,538 tons/year was used based upon the assumed availability and the GatesCycle predicted performance analysis
- Sufficient quantities of biomass feedstock are available for each application as well as sufficient well or surface water for process and purification system requirements
- Operating availability of the biomass combustion system will be 85% on an annualized basis.
- A backup diesel generating system was assumed to operate on diesel or biodiesel during the 15% of downtime and also to supply power for the biomass facility startup. A fuel cost of $3.50/gallon for the backup generating system.
- The financing was assumed to be 100% debt financed through World Bank or other similar sources. Alternatively, a portion of the facility cost can be assumed to be an equity contribution with return to the equity financing organization at the equivalent debt rate.
- An annual finance rate of 8% was used
- Typical financing issuance costs, insurance and debt service reserves are included. However, it is likely that a supervising organization will ultimately coordinate and arrange for a system of this nature and complexity to be financed and installed. The costs of the supervising organization, including development, oversight during construction and oversight during long-term operations were not included.

A system as proposed herein that includes both electric production and MVC based water purification is therefore deemed to be both technically and economically feasible. The system would provide ample electricity and purified water for a community of approximately 40,000 people assuming:

- 1,000 KW of the total electric output is used for public facilities and industry
- 250 watts of average electrical load per home
- 4 people on average per home
- 1 gallon of purified drinking water per person

Alternatively, the system would support a community of 20,000 people on the following assumptions:

- 1,000 KW of the total electric output is used for public facilities and industry
- 500 watts of average electrical load per home
- 4 people on average per home
- 2 gallons of purified drinking water per person

The facility would also provide employment for an estimated 50 people including operating staff and fuel gathering personnel. The electrical supply allowance in the above projection for public facilities and industry can support a multitude of uses including schools, crop irrigation, public buildings, health facilities, sanitary waste effluent treatment and manufacturing. It is important to note that installation of a facility with this type of production and capability should be viewed in the context of a community master plan that also integrates:

- ✓ Other infrastructure for delivery of power, water and sanitary waste treatment
- ✓ Support for agricultural production improvements for not only local consumption, but also export opportunities
- ✓ Addition of manufacturing facilities to support the local economy given the availability of reliable power and water
- ✓ Health care and education facilities

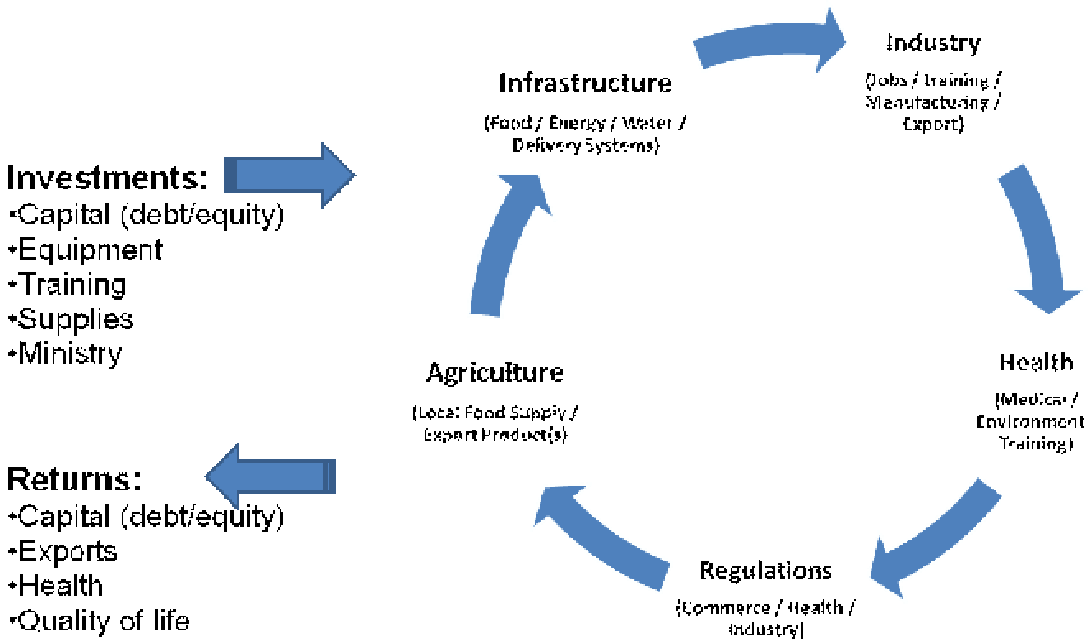
Future Work:

Future work should focus on utilizing a system of this design to support a master plan that would ultimately transform an impoverished community to one that is self sustaining with:

1. Ample food supply
2. Ample energy and purified water
3. Appropriate sanitary waste treatment
4. Manufacturing and industry
5. Retail sales
6. Exports of agricultural and manufactured products
7. Jobs
8. A centralized utility that owns the electric and water purification facility with sales of those utilities to industry and private individuals
9. Public schools
10. Health care facilities

A diagrammatic illustration of a conceptual master plan that would be implemented to transform an impoverished community is shown in Figure 4 below

Figure 4 – Conceptual Community Transformation Diagram



Future work should also focus on the following:

1. Evaluation of available biomass fuel supplies for regions where impoverished communities will be located. This fuel study should identify the types and quantities of various biomass feedstock that could be available.
2. Evaluation of moisture contents and predicted fuel heating values for the composite fuel streams determined from the above fuel supply study.
3. Evaluation of fuel drying system sizing and costs where fuel moisture contents will be high, including drying systems that utilize the waste heat in the flue gas being discharged to atmosphere for drying
4. Evaluation of alternate facility sizes. Given the large amount of biomass required for a facility of this size, smaller sizes such as 50 TPD and 100 TPD should be evaluated.
5. Refinement of the capital and operating cost assumptions that the economic projections were based upon. This cost analysis should also be completed for alternate smaller facility sizes
6. Evaluation of alternate water purification systems which may be lower in capital and operating costs
7. Completion of a load study to determine predicted “peak” and “off-peak” load requirements to balance the electrical loads on a 24 hour basis. This will likely modify the sizing recommendations of the water purification system so that purified water production can occur during off-peak periods where electrical demand is lowest such as during the night and weekends.

Recognition:

Special thanks are given to the following individuals and organizations for their support in completion of this study:

1. Mr. Gregg Tomberlin who completed the performance modeling and technical evaluation of various power cycle and water treatment system options for producing purified drinking water.
2. Novo Energy for providing technical information, performance information, capital cost estimates and economic proforma assistance
3. Encon Evaporators for their assistance with technical, performance and economic information for various water treatment systems including MVC systems
4. Baylor University for hosting the "Bottom-Up Approaches to Global Poverty Conference" and inviting the presentation of results of this study.

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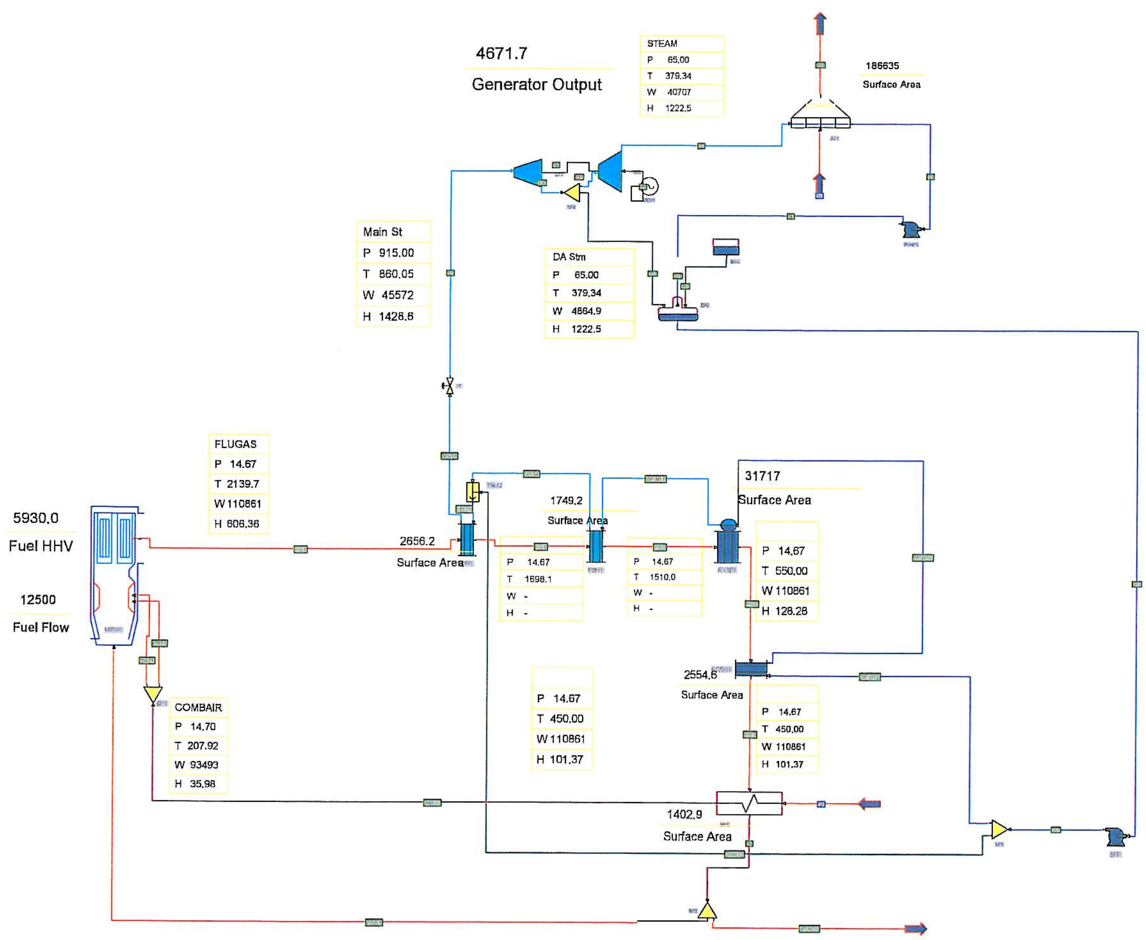
6. L.L. Wright, M.A. Walsh, M.E. Downing, L.A. Kszos, J.H. Cushman, G.A. Tuskan, S.B. McLaughlin, V.R. Tolbert, J. Scurlock, J. and A.R. Ehrenshaft, Biomass Feedstock Research and Development for Multiple Products in the United States, 1st World Conference and Exhibition on Biomass for Energy and Industry, Sevilla, Spain, 6/5-9/2000

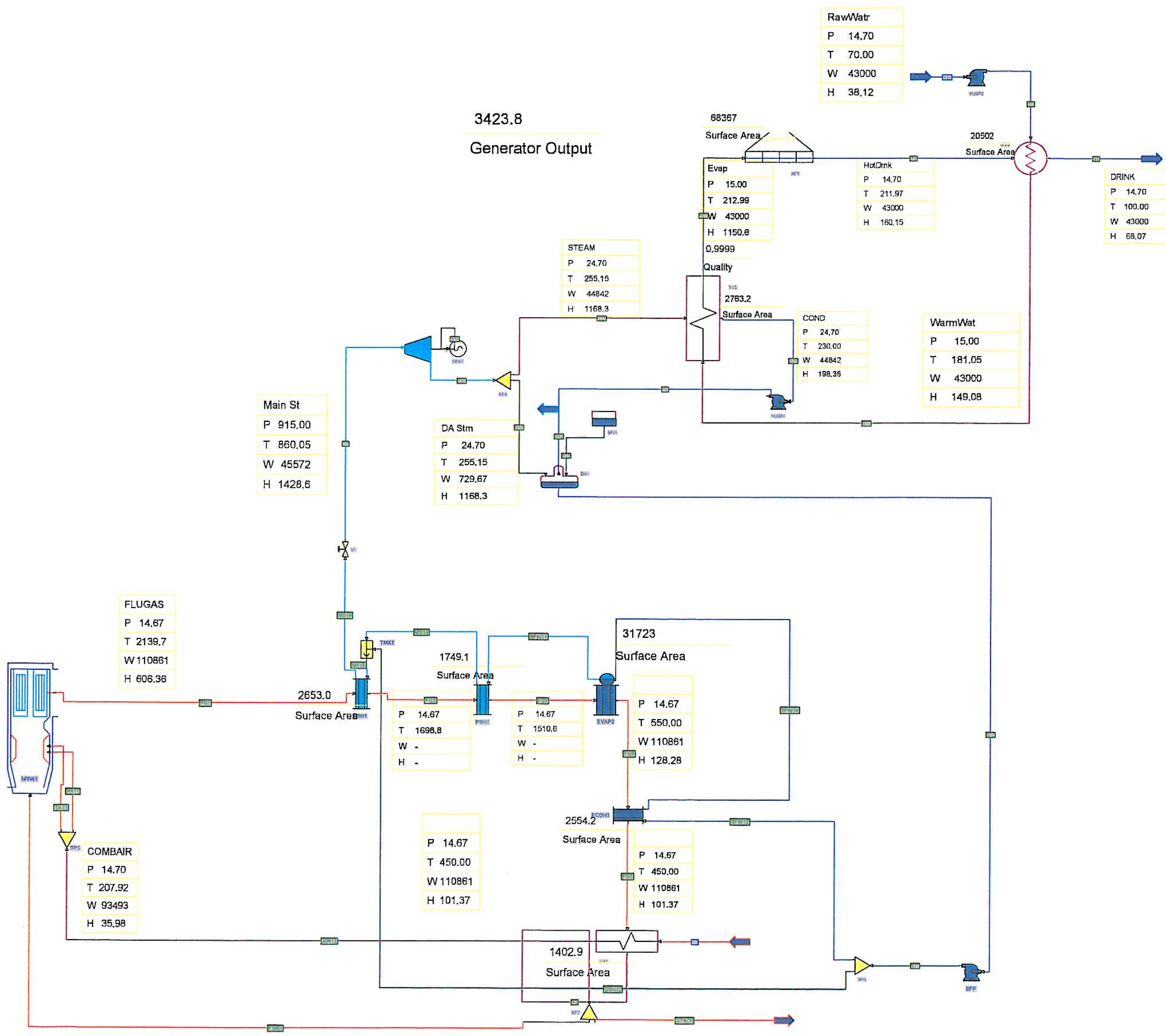
Appendix A

Heat and Mass Balance Diagrams

150 TPD - BIOMASS FIRED POWER GENERATION W/O DISTILLATION



150 TPD - BIOMASS FIRED POWER GENERATION WITH DISTILLATION



Appendix B

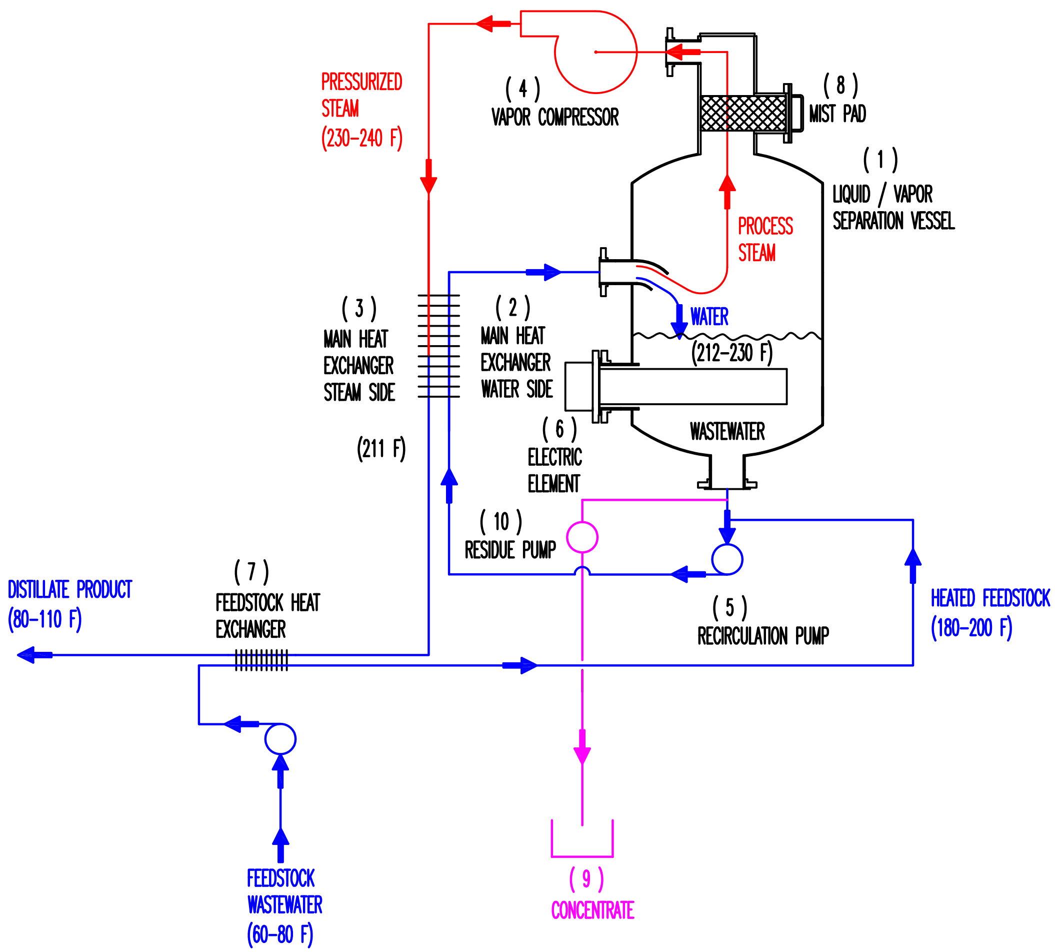
MVC Manufacturer Information

ENCON

Mechanical Vapor Compression (MVC) Evaporator

Feature	Benefit
Handles a wide range of waste steams simultaneously:	**Solve Wastewater Problems with a Single System**
Very clean distilled water product:	**Can Recycle or Discharge to Sewer**
Typical operating cost of $0.01 – 0.02 per gallon:	**Excellent Financial Justification**
Easy to Install and Operate :	**Minimal Manpower Requirement**
Handles volumes up to 43,000 gallons per day:	**Cost Effective Solution for Large Volume Applications**

ENCON MVC FLOW DIAGRAM AND PRINCIPLE OF OPERATION



PRINCIPLE OF OPERATION

1. UNHEATED WASTEWATER IS FED TO THE LIQUID VAPOR SEPARATION TANK (1) AND IS HEATED TO BOIL BY ELECTRIC ELEMENT (6).

2. RECIRCULATION PUMP BEGINS CIRCULATING HEATED WATER THROUGH MAIN HEAT EXCHANGER (2) AND BACK INTO SEPARATION TANK (1).

3. STEAM FLOWS UP TROUGH MIST PAD (8) TO INLET SIDE OF VAPOR COMPRESSOR (4).

4. COMPRESSED STEAM FROM VAPOR COMPRESSOR (4) IS FORCED THROUGH THE STEAM SIDE OF MAIN HEAT EXCHANGER (3) GIVING UP LATENT HEAT TO THE COUNTER FLOWING WATER FROM SEPARATION TANK (1).

5. HIGH TEMPERATURE DISTILLATE FLOWS OUT OF MAIN HEAT EXCHANGER (3) TO FEEDSTOCK HEAT EXCHANGER (7) GIVING UP SENSIBLE HEAT TO FEEDSTOCK WASTEWATER.

6. UPON REACHING STEADY STATE COLD FEEDSTOCK WASTEWATER IS FED AT A CONSTANT RATE THROUGH FEEDSTOCK HEAT EXCHANGER (7) TO RAISE TEMPERATURE BEFORE FEEDING TO RECIRCULATION LOOP.

7. CONCENTRATE IS PERIODICALLY DISCHARGED TO CONCENTRATE TANK (9) THROUGH RESIDUE PUMP (10).

ENCON

ENERGY CONSCIOUS INNOVATION

STANDARD FEATURES OF ENCON MVC SYSTEMS

* Control Panel that meets NEMA 4 standards. Lighted panel includes easy to read Interactive Graphical Display, 120 V/1 phase receptor and Modem/Ethernet hub that allows for remote access to PLC by ENCON Service Engineers.

* On-board diagnostics that monitor system inputs for correct operation and system shutdown.

* Feed/Clean in Place Pump, Recirculation Pump, Residue Pump, Water Injection and Distillate Pump

* Dual Strainers for incoming fluid feed line with fluid diverter valve. Allows system to continue running while either strainer is taken out of service. Both strainers integrated into PLC to notify operator of need to clean.

* Feed Stock Heat Exchanger with Pressure and Temperature Sensors to monitor system performance and initiate Clean in Place Operation.

* Main Heat Exchanger with Pressure and Temperature Sensors to monitor system performance and initiate Clean in Place Operation.

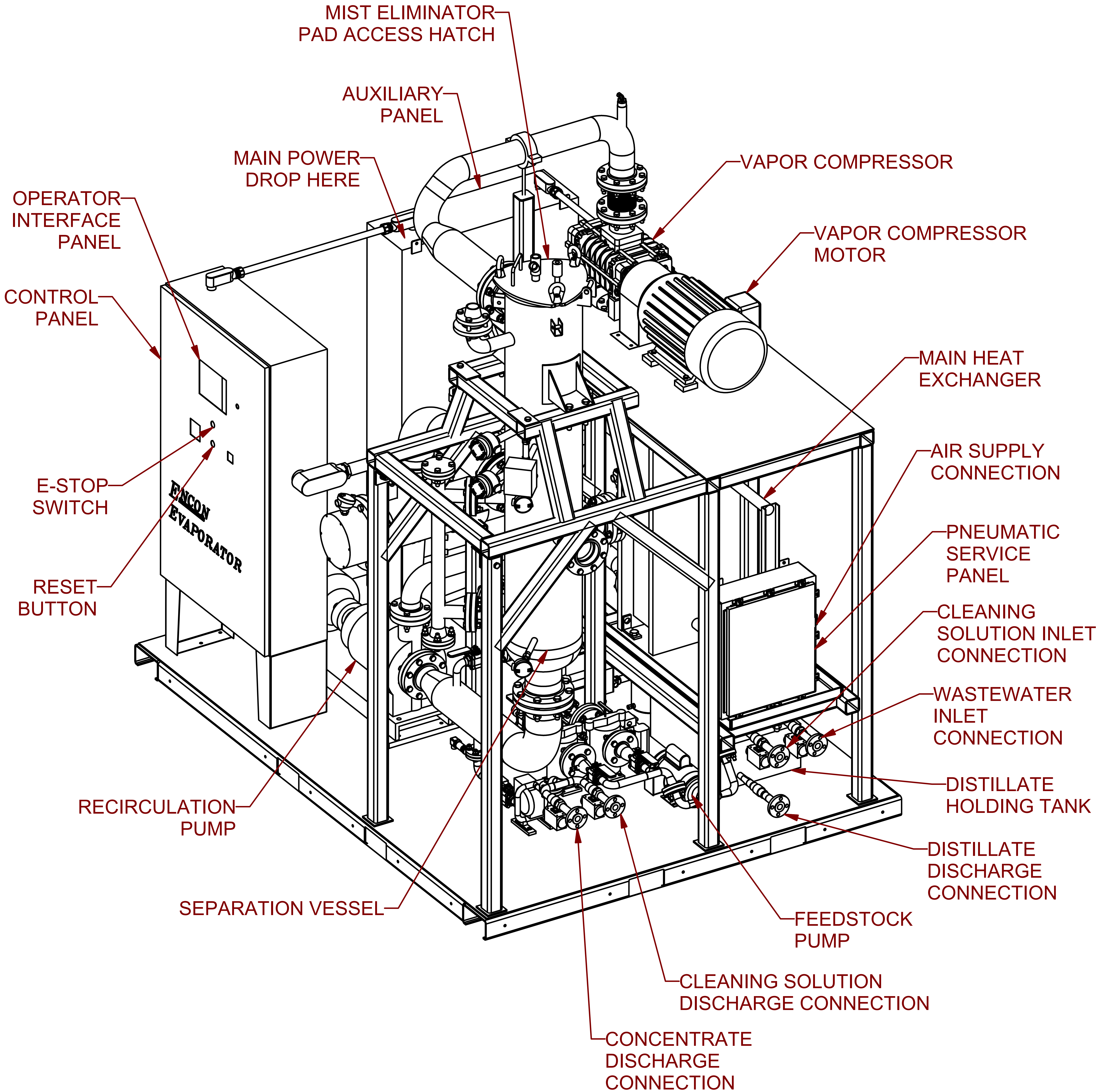
* Separation Vessel with the following:
    - Low Watt Density Heating Element(s)
    - Low Fill Level Control
    - High Fill Level Control
    - Foam Indicators
    - Temperature Sensors for wastewater in Separation Tank and Steam temperature above fluid
    - 1 Separation Tank Pressure Sensor to enable PID loop for heating element.
    - Large Manhole Cover to access inside of Separation Tank.
    - Dual Density Mist Pad to capture unwanted contaminants in steam.
    - Air Vent
    - Vacuum Breaker
    - Rupture Disk
    - Discharge Line with High Temperature Residue Pump for Automatic Residue Removal

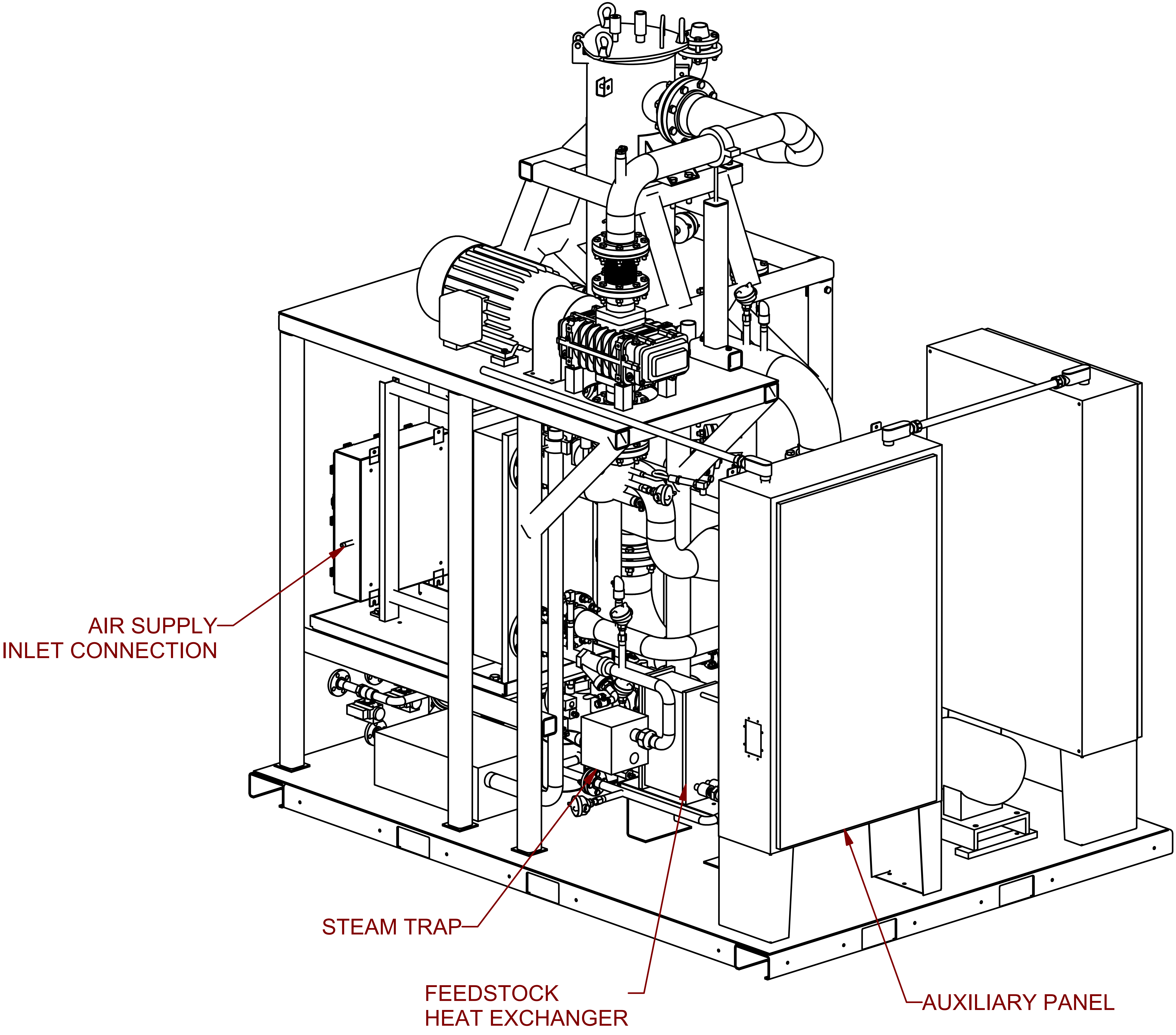
* Pressure Vent and Sensor on Steam Line between discharge side of Vapor Compressor and steam inlet to distillate side of Main Heat Exchanger.

* Pressure and Temperature Sensors, Strainer and Distillate Line between outlet of Main Heat Exchanger and inlet of Feed Stock Heat Exchanger.

* Distillate Receiving Tank for condensate discharge from Feed Stock Heat Exchanger. Tank includes 2 Level Sensors and Air Diaphragm Distillate Pump for water injection.

ENCON Evaporators
97 Eddy Road, Unit #6
Manchester, NH 03102-3226
Ph: 603-624-5110 Fax: 603-627-9520
www.evaporator.com - sales@evaporator.com


MIST ELIMINATOR
PAD ACCESS HATCH
AUXILIARY
PANEL
MAIN POWER
DROP HERE
OPERATOR
INTERFACE
PANEL
CONTROL
PANEL
VAPOR COMPRESSOR
VAPOR COMPRESSOR
MOTOR
MAIN HEAT
EXCHANGER
AIR SUPPLY
CONNECTION
PNEUMATIC
SERVICE
PANEL
CLEANING
SOLUTION INLET
CONNECTION
WASTEWATER
INLET
CONNECTION
DISTILLATE
HOLDING TANK
DISTILLATE
DISCHARGE
CONNECTION
FEEDSTOCK
PUMP
CLEANING SOLUTION
DISCHARGE CONNECTION
CONCENTRATE
DISCHARGE
CONNECTION
SEPARATION VESSEL
RECIRCULATION
PUMP
RESET
BUTTON
E-STOP
SWITCH
ENCON
EVAPORATOR



AIR SUPPLY
INLET CONNECTION
STEAM TRAP
FEEDSTOCK
HEAT EXCHANGER
AUXILIARY PANEL

ENCON MVC EVAPORATORS

Standard Models (See Nomenclature Clarification in Adjacent Columns w/Options Below)	Nomenclature Clarification (Based on MVC600-333-33A-A1)	System Dump Capacity (Gallons)	Dimensions (Inches) Length x Width x Height	Electric Heaters For Startup (kW)	Compressor Horsepower	Power/ Main Circuit Size(Amps)
MVC40-333-33B-Z1	**MVC600 : Distillation Rate (gallons/hour)**	20	102 x 78 x 132	10	7.5	480v/3pH/40A
MVC75-333-33B-Z1	**MVC600-3 : 316SS Feed Pipe Material**	25	102 x 78 x 153.5	10	15	480v/3pH/60A
MVC150-333-33B-A1	**MVC600-33 : 316SS Vessel/Recirc. Pipe Material**	55	120.5 x 88 x 185	24	30	480v/3pH/100A
MVC300-333-33B-A1	**MVC600-333 : 316SS Residue Pipe Material**	119	132 x 96 x 197	30	60	480v/3pH/175A
MVC450-333-33B-A1	**MVC600-333-3 : 316SS Recir. Pump Material**	183	150 x 117 x 200	(2)30	75	480v/3pH/200A
MVC600-333-33A-A1	**MVC600-333-33 : 316SS Main Heat-X Material**	266	150 x 117 x 215	(2)30	150	480v/3pH/400A
MVC900-333-33A-A1	**MVC600-333-33A : Ductile Iron Compressor Material**	407	175 x 127 x 248	(3)30	150	480v/3pH/500A
MVC1200-333-33A-A1	**MVC600-333-33A-A : Allen Bradley PLC**	570	175 x 139 x 248	(4)30	200	480v/3pH/650A
MVC1500-333-33A-A1	**MVC600-333-33A-A1 : 480Volt/3PH/60Hz Power Supply**	715	181 x 139 x 265	(4)30	250	480v/3pH/650A
MVC1800-333-33A-A1		862	205 x 162 x 287	(5)30	300	480v/3pH/700A

AVAILABLE OPTIONS

MATERIALS OF CONSTRUCTION FOR PIPING, VESSEL, HEAT-X

- (3) 316 Stainless Steel (Standard)
- (6) 6% Moly Alloy (Super Stainless)
- (2) Hastelloy C
- (5) Duplex Stainless (N/A Heat-X)
- (7) FRP (N/A Heat-X)

VAPOR COMPRESSOR

- (A) Ductile Iron (Standard)
- (B)Stainless Iron Lobes(Models40-450)
- (C)316Stainless (Models 600-1800)

ELECTRICAL SUPPLY

- (1)480V/3PH/60HZ (Standard)
- (2)380V/3PH/50HZ
- (3)575V/3PH/60HZ
- (4)380v/3PH/60HZ

MISCELLANEOUS

- Anti-Foam Feed System
- Cone Bottom Holding Tank w/ Stand
- Upgrade Operator Interface to 15" diagonal
- Vapor Compressor Sound Deadening
- Conductivity Probe for monitoring and controlling solution concentration in Separation Vessel

FABRICATION:

Separation Vessel: 3/16" Plate, Designed to ASME Standard for 15PSIG, Side and Top Access with Davit Arms, 2 Site Glasses, Internal Calming Cone

Heating Elements: Low Watt Density, 150lb. Flange,

Mist Eliminator Pad: Dual Density, 316SS/Fiberglass Blend, Rated 10micron/2 micron

Skins: Aluminum clad (Separation Vessel and pipe insulation), Fabric with Velcro straps (heat exchangers and Vapor Compressor Insulation, optional)

Insulation: 2" Thickness, All sides rated to 900°F

QUALITY:

Pressure Test: Stamped and coded as necessary up to 15 PSIG
Leak Test: Dye penetrant test on welded tank
I/O Simulation: To ensure accuracy of controls

WARRANTY: One Year parts and workmanship

CONTROLS:

PLC Controller: Graphical Operator Interface Display
- Pull down menus, scrolling messages, alarms, E-stop
- Modem/Ethernet hub for ENCON direct connection
- Watertight Control Panel Enclosure (NEMA 4,12,13)

Temperature Control/Monitoring Devices:
2 - Eight channel analog input cards
6 - Type J Thermocouples

Level Control Inputs:
4 - Frequency Shift Level Probes
1 - Analog Level Transmitter
1 - Feedwater Holding Tank Float Switch

Pressure Inputs:
1 - Separation Vessel Vapor
2 - (I/O) for Main Heat Exchanger Steam Side
2 - (I/O) for Main Heat Exchanger liquid recirculation side

Probes and Drives:
- RF Capacitance for foam detection & Separation Vessel shutdown
- *Variable Frequency drives:*
  1 for Recirculation Pump
  1 for Feedstock Pump
  1 for Vapor Compressor

Control Scheme: Auto-Fill, Auto-Dump, Clean-in-Place