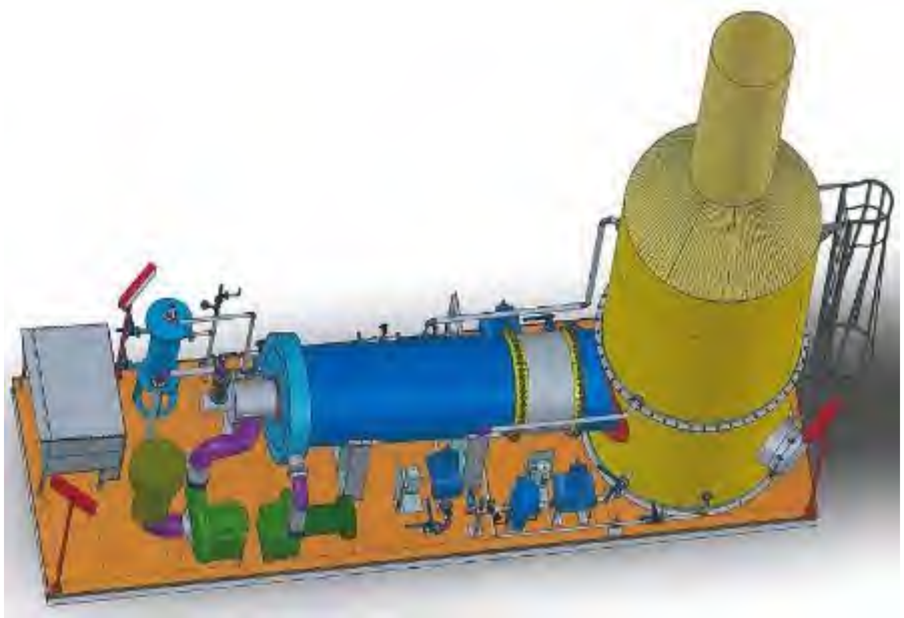
Industrial Wastewater Disposal System

Direct Evaporation Technology Discussion

Sustainable Solution for Disposal of Industrial Wastewaters

Ken Burris
Chief Technology Officer
Cell: (832) 713-5236
Email: kenburris@aguaraider.com

Introduction to AguaRaider Direct Evaporation Technology



To more effectively understand the benefits and advantages of the AguaRaider Direct Evaporation Technology, it is helpful to review the thermodynamic principles employed and the problems that can occur with evaporation technology. The following will be followed by a detailed description of the AguaRaider Technology, which should highlight our benefits and advantages.

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Vaporization Technology

- **Phase transition from liquid phase to gas phase**
- **Vaporization** is the way molecules change from a solid or liquid to a gas. For **vaporization** to happen, heat is necessary. Heat is energy. Some liquids change to a vapor at room temperature by pulling heat from the environment.
- **Two Types of Evaporization**
  - **Evaporization -** occurs from the surface of a liquid into a gaseous phase that is not saturated with the **evaporating** substance.
  - **Boiling –** occurs below the surface; characterized by bubbles of saturated vapor forming in the liquid phase.

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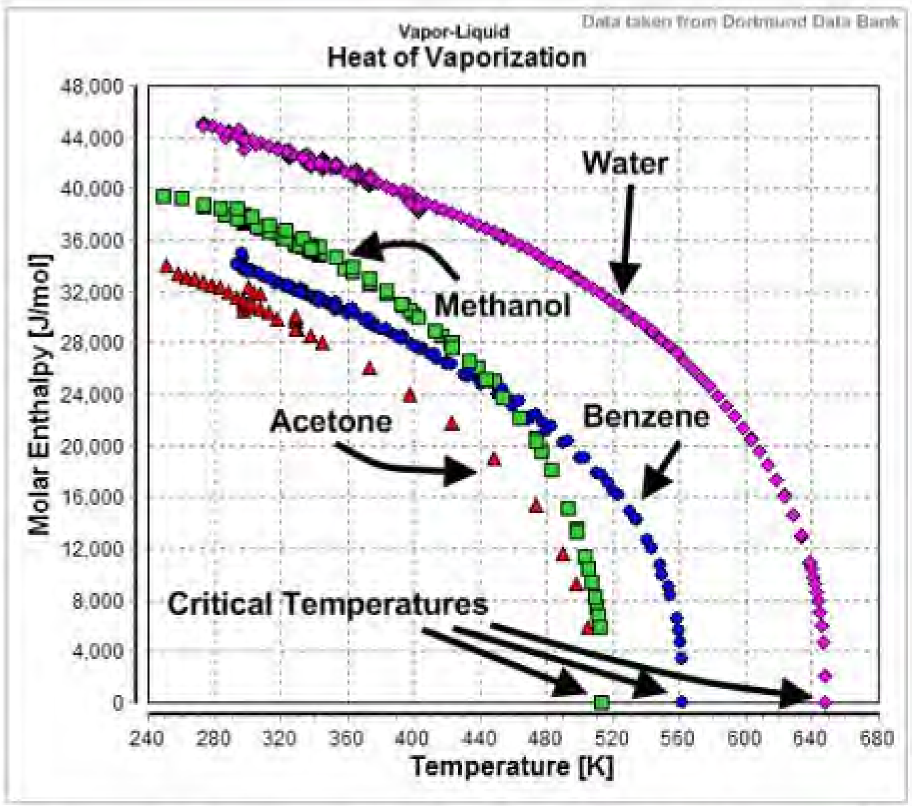
Enthalpy of Vaporization

The **enthalpy of vaporization**, (symbol ΔH_{vap}) also known as the **(latent) heat of vaporization** or **heat of evaporation**, is the energy (enthalpy) that must be added to the substance, typically a liquid, to transform a quantity of that substance into a gas. The enthalpy of vaporization is a function of the pressure at which that transformation takes place.



Temperature-dependency of the heats of vaporization for water, methanol, benzene, and acetone.

Enthalpies of Vaporization of the Elements

V·T·E

Enthalpies of vaporization of the elements

Group → / ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H 0.44936																	He 0.0845
2	Li 145.92	Be 292.40											B 489.7	C 355.8	N 2.7928	O 3.4099	F 3.2698	Ne 1.7326
3	Na 96.96	Mg 127.4											Al 293.4	Si 300	P 12.129	S 1.7175	Cl 10.2	Ar 6.447
4	K 79.87	Ca 153.6	Sc 314.2	Ti 421	V 452	Cr 344.3	Mn 226	Fe 349.6	Co 376.5	Ni 370.4	Cu 300.3	Zn 115.3	Ga 258.7	Ge 330.9	As 34.76	Se 26.3	Br 15.438	Kr 9.029
5	Rb 72.216	Sr 144	Y 363	Zr 581.6	Nb 696.6	Mo 598	Tc 660	Ru 595	Rh 493	Pd 357	Ag 250.58	Cd 100	In 231.5	Sn 295.8	Sb 77.14	Te 52.55	I 20.752	Xe 12.636
6	Cs 67.74	Ba 142	*	Hf 575	Ta 743	W 824	Re 715	Os 627.6	Ir 604	Pt 510	Au 334.4	Hg 59.229	Tl 164.1	Pb 177.7	Bi 104.8	Po 60.1	At 27.2	Rn 16.4
7	Fr n/a	Ra 37	**	Rf n/a	Db n/a	Sg n/a	Bh n/a	Hs n/a	Mt n/a	Ds n/a	Rg n/a	Cn n/a	Uut n/a	Fl n/a	Uup n/a	Lv n/a	Uus n/a	Uuo n/a

*	La 414	Ce 414	Pr n/a	Nd n/a	Pm n/a	Sm n/a	Eu n/a	Gd n/a	Tb n/a	Dy n/a	Ho n/a	Er n/a	Tm n/a	Yb n/a	Lu n/a
**	Ac n/a	Th 514.4	Pa n/a	U n/a	Np n/a	Pu n/a	Am n/a	Cm n/a	Bk n/a	Cf n/a	Es n/a	Fm n/a	Md n/a	No n/a	Lr n/a

Enthalpy in kJ/mol, measured at their respective normal boiling points

0–10 kJ/mol | 10–100 kJ/mol | 100–300 kJ/mol | >300 kJ/mol

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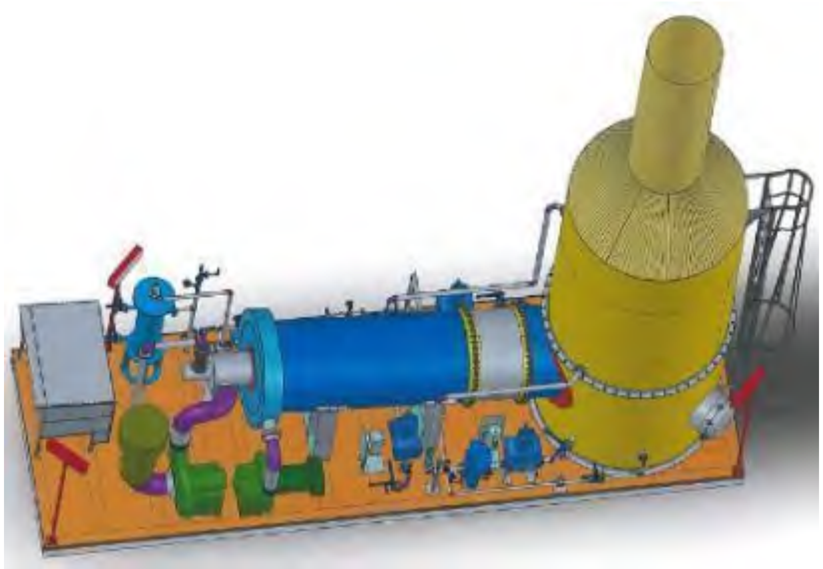
- As noted in the previous periodic table a table, the elements of primary interest in evaporation is H (**Hydrogen – 0.44936 enthalpy of evaporization**) and O (**Oxygen – 3.4099 enthalpy of evaporization**).
- **Controlling the temperature during the Evaporization process** of the water will maximize the probability of evaporating H_2O and minimize vaporizing other elements in the water.
- **Thermocouples in the AguaRaider stack allow the system to monitor and control the temperature and heating of the air from the firetube**.



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Enthalpy

- Measure of total energy of a thermodynamic system
- A state of function
- Includes
  - Internal energy (energy required to create a system)
  - Amount of energy required to establish system's pressure and volume
- Enthalpy is not necessarily heat
  - Heat is defined as thermal energy in transmit
  - For the description that enthalpy is in-fact heat to be valid, no energy exchange must occur with environment other than **heat** or **expansion work**

Enthalpy of Vaporization (EOV)

- Enthalpy change required to completely change the state of one mole of substance between liquid and gaseous states
- Energy required to transform a given quantity of a substance from a liquid into a gas at a given pressure
- Usually measured at boiling point of substance

Characteristics of Enthalpy of Vaporization

- It is temperature dependent
- EOV decreases with increase in temperature
- EOV diminishes completely at critical temperature beyond which liquid and vapor phases no longer co-exist

Evaporization as a Unit Process

- It is the removal of a relatively large amount of liquid (solvent) to reduce the volume of the liquid and obtain concentrated solution
- Evaporization is a thermal separation process to heat the liquid to produce gas vapor. The volume of the liquid is reduced and the dissolved solids in the liquid are concentrated
- Evaporation is a type of vaporization of a liquid that occurs on the surface of the liquid.
- Heating of the liquid will be necessary to provide the latent heat of vaporization, and in general, the rate of evaporation is controlled by the rate of heat transfer

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Theory of Evaporation in Open System

- Evaporation is the process of liquid turning to gas by the following mechanism
  - The Liquid is made up of many molecules (organic and inorganic) that are in constant random motion
  - These molecules collide with each other to gain or lose kinetic energy from or to other molecules
  - The molecules at the surface of the liquid which have high enough kinetic energy to break the bonds with other molecules will be able to change from liquid to gaseous state and escape the surface of the liquid.
  - Since the molecules with higher kinetic energy have moved out of the liquid, the average kinetic energy of the liquid drops which in turn means that the temperature of water will decrease as well (evaporative cooling)

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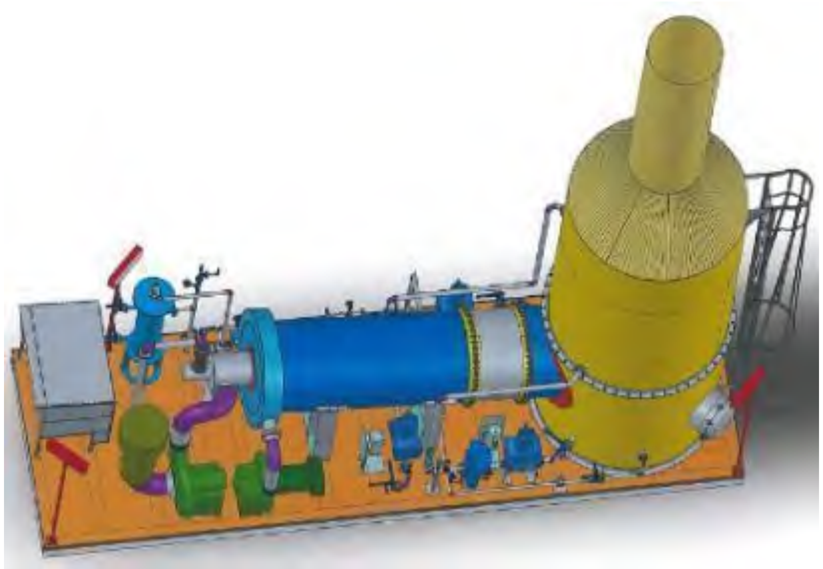
- As noted in the previous slide, Evaporization occurs at the ‘surface’ of the liquid.
- The AguaRaider technology utilizes a spraying of water droplets into the heated air flow from the firetube.
- The more optimum volume versus surface area ratio of the AguaRaider water droplets results in a more efficient evaporation and less energy required for the evaporation process.



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Factors Affecting the Rate of Evaporation

- Rate of Evaporation is affected proportionally by:
  - Temperature (indicator of kinetic energy)
  - Pressure
  - Surface Area
- Rate of Evaporation is inversely affected:
  - Intermolecular Forces (which are affected by matter concentration, i.e. dissolved salts, dissolved gases, dissolved organics, etc.
  - Suspended solids in the liquid will also adversely affect rate of evaporation.
  - Humidity
  - Wind

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Temperature

- The rate of evaporation of liquids varies directly with temperature.
- With the increase in temperature, fraction of molecules having sufficient kinetic energy to escape out of the surface also increases.
- Thus with the increase in temperature, rate of evaporation also increases.

Surface Area

- Molecules that escape the surface of the liquids constitute the evaporation. Therefore in bulk liquids, the larger surface area contributed accelerating evaporation.
- Exposed Surface Area
  - The rate of evaporation is directly proportional to the exposed surface area.
  - The greater the exposed surface, the faster the evaporation. This is because water molecules need to be at the surface of the liquid to evaporate.
  - With a large surface area, more liquid molecules can be at the surface and therefore more liquid molecules can evaporate.

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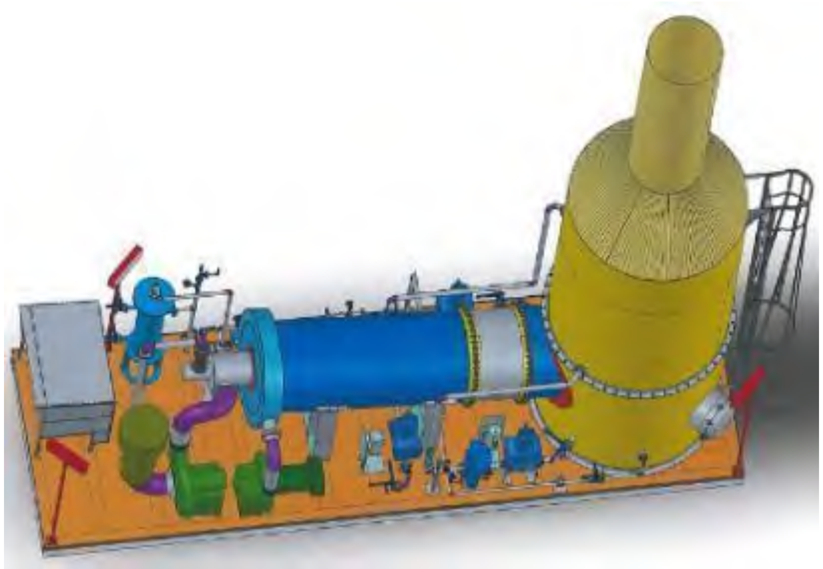
- **Temperature**
  - The combination of AguaRaider water droplets and temperature achieve the optimum evaporation of water, without unnecessary waste of energy
- **Surface**
  - AguaRaider maximizes the surface area using water droplets to the energy input to conserve energy required (gas fuel source)



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Pressure

- If pressure is applied on the surface of a liquid, evaporation is hindered.
- With Evaporation being affected by the pressure exerted on the evaporating surface of the liquid, lower pressure on open surface of the liquid results in higher rate of evaporation.

Flow Rate of Air

- The rate of evaporation of liquids depends upon the flow of air currents above the surface of the liquid.
- Air current flowing over the surface of the liquid take away molecules of the substance in vapor state there by preventing condensation.
- In addition, it gives the space for new molecules of liquid in the form of water vapor to be produced.

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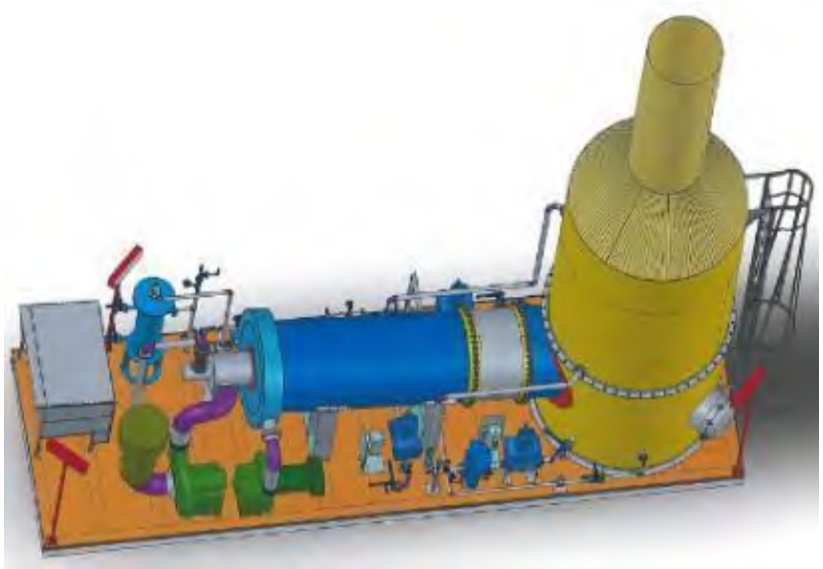
- **Pressure**
  - AguaRaider process design using a heated air flow around the droplets, this pressure at the surface is minimal to results in higher rate of evaporation
- **Flow Rate of Air**
  - AguaRaider process design using the flow of heated air around the water droplets to sweep the evaporated water away from the surface allowing the space for additional water evaporation



Inter-Molecular Forces

- The stronger the forces keeping the molecules together in the liquid or solid state the more energy that that must be input to evaporate.
- The magnitude of the inter-molecular forces of attraction in liquid determine the speed of evaporation.
- Weaker the inter-molecular forces of attraction, larger is the extent pf evaporation.

Humidity of the Air

- Humidity is the amount of water vapor found in the air, and is referred to as Relative Humidity. It is expressed in percentage.
- The Relative Humidity of the air has a direct effect on the rate of evaporation of liquids. If the air has high humidity, the rate of evaporation will be slower.

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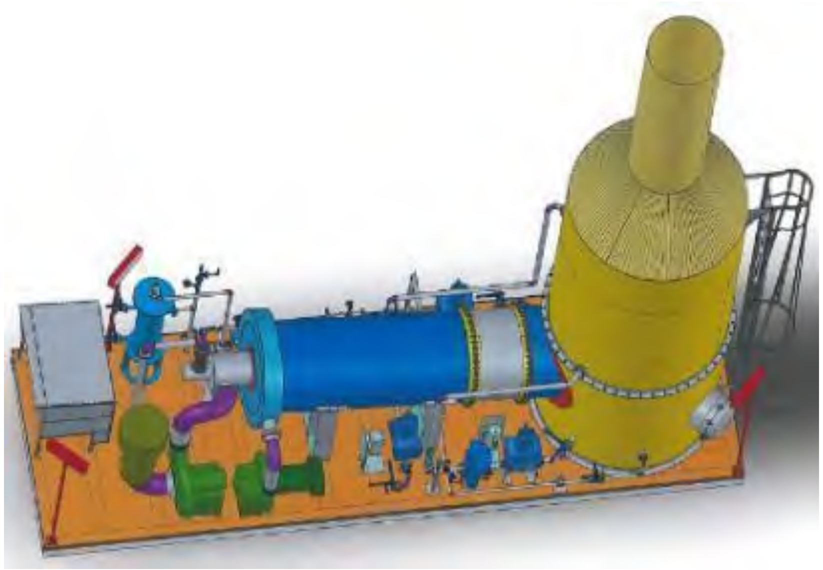
- **Inter-Molecular Forces**
  - While AguaRaider feed water can have elevated dissolved solids in the water, through the AguaRaider process design, the energy, air flow and temperatures are optimized for water evaporation to minimize the influence of IMF.
- **Humidity of the Air**
  - AguaRaider stack design minimizes the influence of the air humidity on the evaporation process. Humidity will influence the condensation of the steam plume exiting the stack.



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Constituents of the Solution

- If the fluid is made up of large charged molecules, the molecules will escape at a slower rate because more energy is required to lift their mass and overcome their electromagnetic interactions with each other to allow the molecules to escape.
- Also, a mixed fluid can evaporate faster or slower depending on how the different molecules interact with each other.

Viscosity of the Solution

- Viscosity is the resistance of a liquid to flow.
- Viscosity increases with increasing strength of inter-molecular forces and decreases with increasing temperature.
- The rate of vaporization increases with increasing temperature, and decreasing strength of inter-molecular forces.
- The viscosity of the solution increases in the process of evaporation, due to concentration of the solute in the solution.
- As a result, increases the boiling point.
- The increased viscosity reduced the heat transfer coefficient, thus slows down the rate of evaporation. Sine the rate of evaporation depends on the heat transfer equation.

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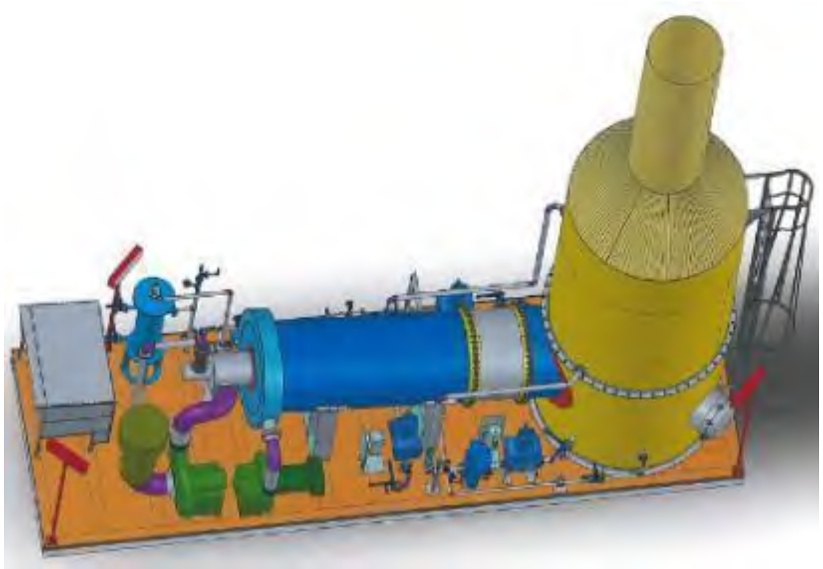
- **Constituents of the Solution**
  - AguaRaider process design uses the appropriate energy, temperature and air flow for water evaporation, avoiding the energy levels that would evaporate the larger molecular constituents that remain in the liquid and fall to the brine concentrate section of the stack.
- **Viscosity of the Solution**
  - This factor has little or no influence in the AguaRaider process design, since the higher viscose fluids are in the brine concentrate section.



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Problems Encountered During Evaporation

- **Entrainment**
  - When a bubble of vapor rises to the surface of liquid and bursts, the liquid film that forms the top of the bubble is usually sprayed as a very fine droplets along with the stream of vapor.
  - Some of them drop back quickly into the liquid from which they came and some settle more slowly.
  - Such finely divided liquid carried along with the stream of vapor is called entrainment.
  - Entrainment may cause (1) losses from the liquid being evaporated and/or (2) contamination be carried out with the vapor.

- **Foaming**
  - Foam is the formation of a stable blanket of bubbles that lies on the surface of the heated liquid.
  - Foaming occurrence is dependent on:
    - The formation at the surface of the liquid of a layer whose surface tension is different from that of the bulk of the liquid
    - The presence of finely divided solids or colloidal material that stabilizes the surface layer

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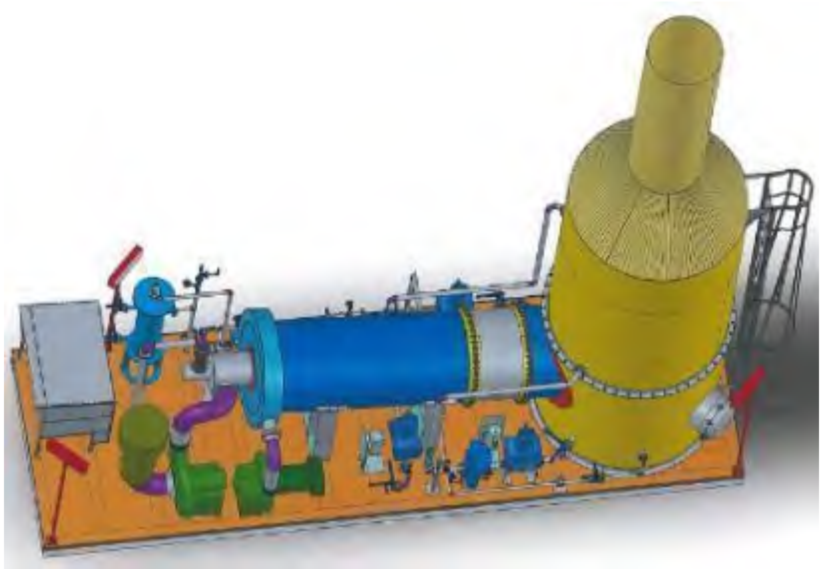
- **Entrainment**
  - AguaRaider process design does not produce ‘bubbles’ of water vapor. The water droplets in the system are heated and water vaporizes from the droplet. The resulting heavier droplet falls to the brine concentrate section.



- **Foaming**
  - Foaming is not a problem in the AguaRaider process design.

Problems Encountered During Evaporation (con't)

- **Scale Formation**
  - Scales are the solid deposits, which accumulate on the heat transfer surfaces during evaporation.
  - Scale has very low thermal conductivity during evaporation.
  - As evaporation proceeds, there is gradual increase resistance to heat transfer due to deposition of scales.
  - Inorganic substances, such as calcium sulfate, calcium hydroxide, sodium carbonate, sodium sulfate and calcium salts of organic acids, have scaling tendency

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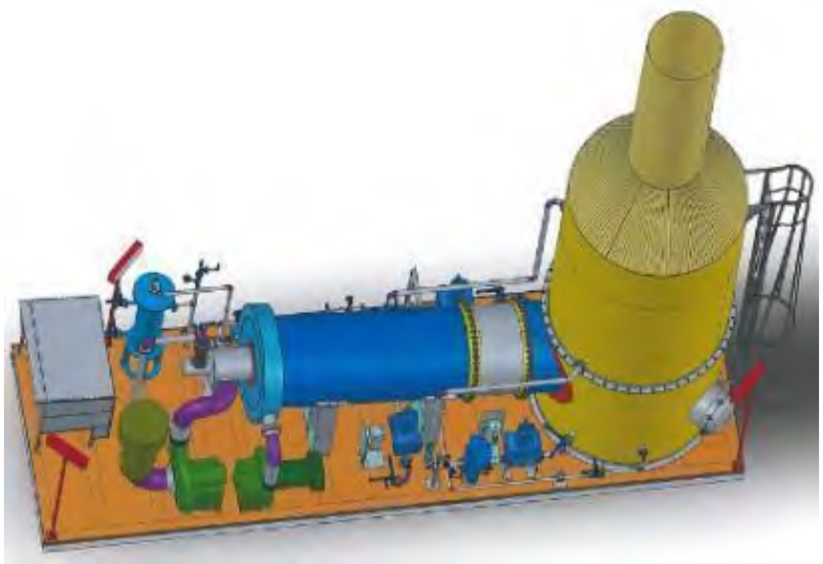
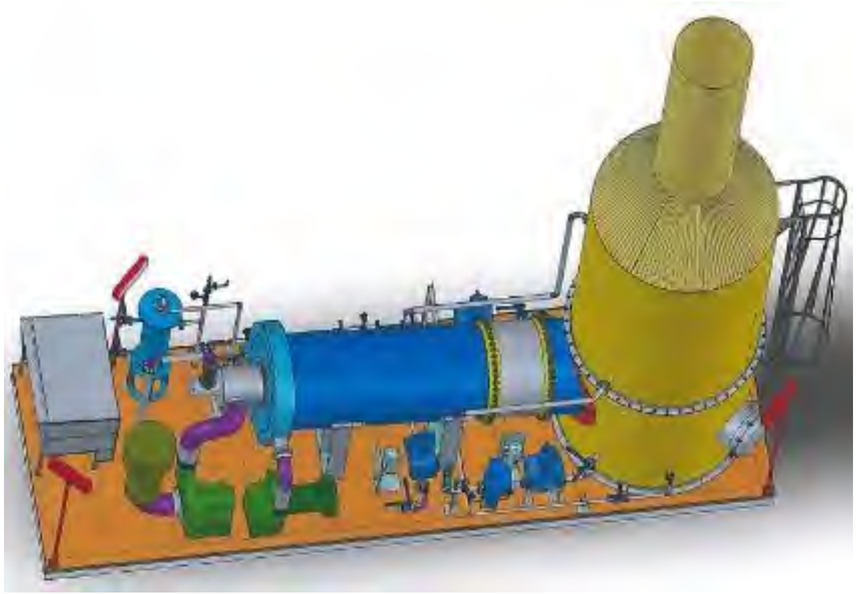
- **Scale Formation**
  - AguaRaider design does not depend on the water touching heat transfer surfaces for Evaporization.
  - Water droplets are formed and come in direct contact with the heated air to evaporate the water from the droplet with an optimum level of heat energy.
  - Scaling in the brine concentrate section is minimized by continuously circulating the volume and withdrawing a specific proportion of concentrate water in relation to influent water flow.



AguaRaider Direct Evaporation Technology Description

- **Gas Side**
  - Natural gas supply(>1,000 BTU; 100psi) is delivered to the ARU unit.
  - The liquid separation unit on-skid will remove any minor liquids from the gas supply.
  - A separate off-skid liquids separation unit may have to be employed, depending on the gas quality.
  - Gas flows to the burner on the firetube.
  - Two blowers provide a balanced flow of air to the burner and firetube to produce the heated air that flows into the stack section.
  - The burner flame only reaches to about mid-way down the firetube.
  - The firetube is lined with refractory material to protect the firetube metal.



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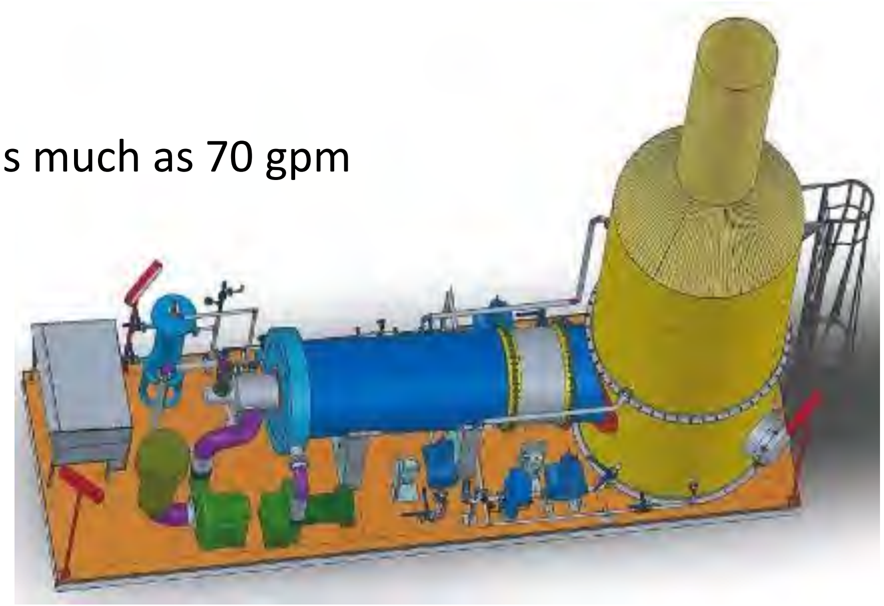
AguaRaider Direct Evaporation Technology Description

- **Water Side**
  - Industrial wastewater is delivered to ARU unit at >30 psi and a flow as much as 70 gpm (2,400 BPD)
  - The water should be filtered for significant suspended solids and be free of oil/grease.
  - **NOTE: On some water sources, a pretreatment module may be required to pretreat/precondition the water to aid in minimizing scaling/deposition.**
  - The source water is pumped to a spray assembly inside the upper level of the stack.



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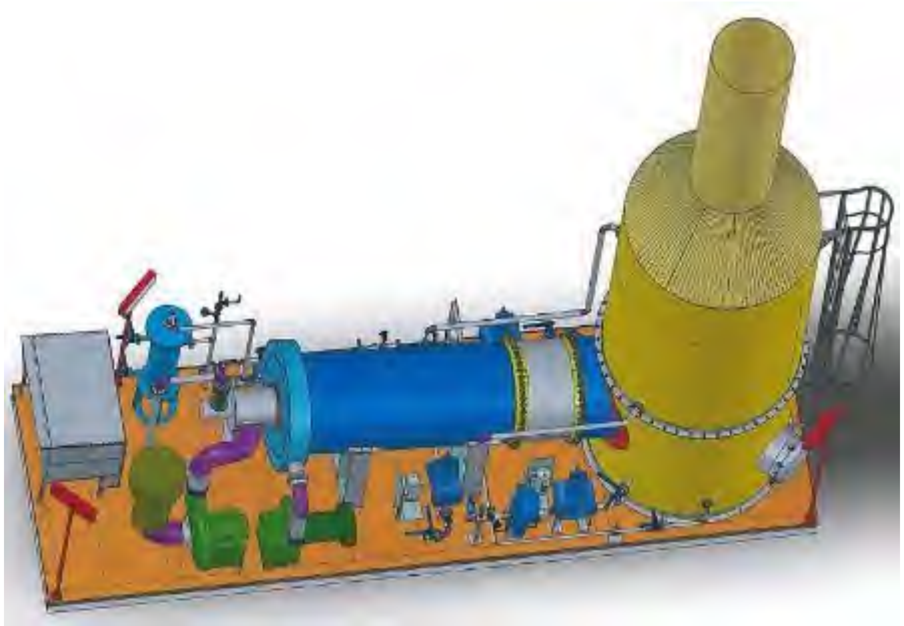
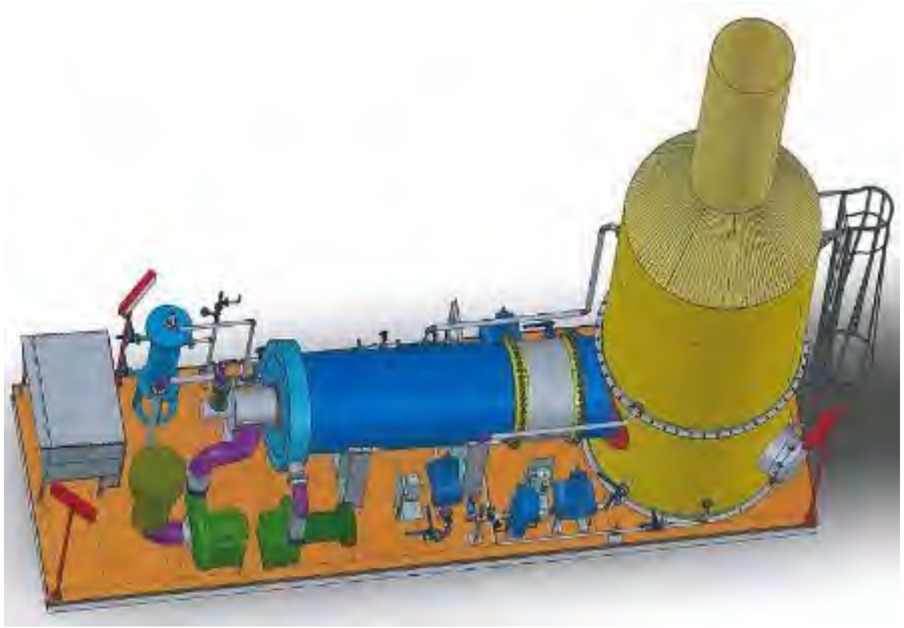
AguaRaider Direct Evaporation Technology Description

- **Water Side** (con't)
  - Water to be evaporated is sprayed directly into the heated air flow from the firetube.
  - Evaporation of the water occurs in the stack and a steam plume flows out the top of the stack.
  - The portion of the water not evaporated and containing the concentrated brine falls to the lower section of the stack.
  - A specific volume of the brine concentrate is pumped back to the stack through a strainer for particulate removal an through another spray assembly into the heated air flow.
  - Another specific volume of brine concentrate is pumped from the ARU proportionate to the influent water flow to achieve the desired % Evaporation Efficiency



AguaRaider Direct Evaporation Technology Description

- **Water Side** (con't)
  - Another specific volume of brine concentrate is pumped from the ARU proportionate to the influent water flow to achieve the desired % Evaporation Efficiency
  - The % evaporation efficiency can be increased by employing pretreatment of the feed water. This could reduce the overall TDS of the water, thus allowing greater % evap efficiency.
  - Additionally, the pretreatment can reduce the total suspended solids (TSS) as much as 90%.
  - Additionally, the organics in the water can be reduced by over 60%, thus reducing the process air emissions inventory.



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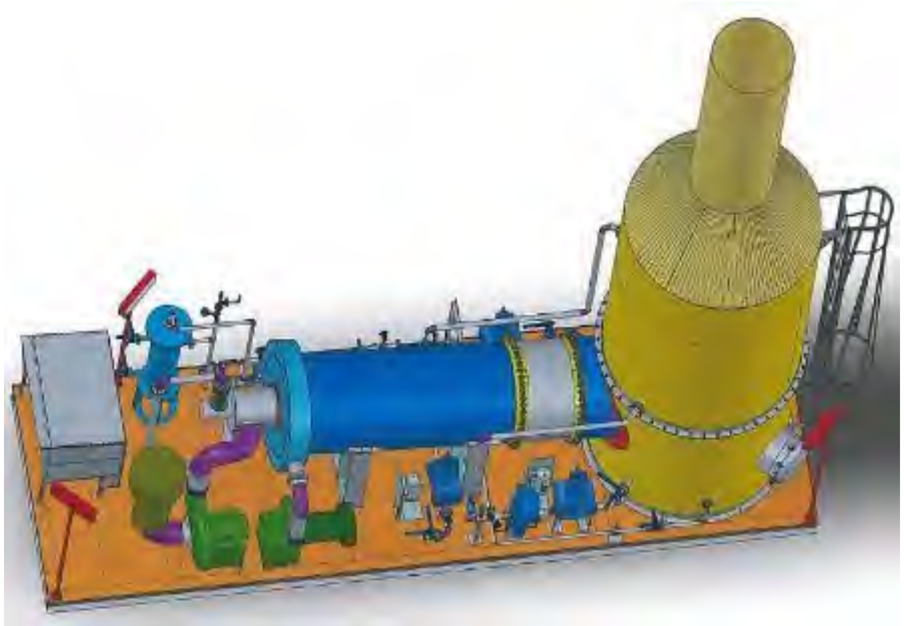
AguaRaider Direct Evaporation Technology Description

- **ARU Controls**
  - The burner controls and all mechanical pumps/blowers are programmed and controlled by the internal PLC and MMI (man machine interface)
  - On the ARU skid are flowmeters and temperature thermocouples to feed information to aid in control of the unit, based on the PLC system.
  - The ARU controls are programmed to provide alerts on specific conditions and potentially shut-down the unit on other conditions.
  - Audible alarms and smart phone communications alert the personnel on-site and remotely to the unit's condition.
  - Operational data is stored for review and transmitted thru smartphone communications.



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AguaRaider Direct Evaporation Technology Advantages

- **ARU Advantages and Benefits**
  - **The evaporation process occurs by direct contact with the heated air flow from the firetube; thus avoiding the problematic heated surfaces employed by others causing scaling and deposition.**
  - **The source water is sprayed into the heated air flow, not to the sides of the stack vessel, producing small droplets of water. This significantly reduces the heat energy (gas) require for evaporation and produces a more effective and efficient evaporation process.**
  - **The spray assemblies are designed to significantly reduce the potential for entrainment or carry-over of dissolved solids.**
  - **The brine concentrate is recirculated to improve the evaporation efficiency of the entire process and maintains movement of the brine fluid to minimize deposition in the bottom of the stack.**
  - **The stack is designed to efficiently push the steam plume and residual heated air out of the stack. Condensation does not occur in the stack.**

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126 N. East St.
Uvalde, TX 78801
(830) 515-5565
www.AguaRaider.com

Ken Burris
Chief Technology Officer
Cell: (832) 713-5236
Email: kenburris@aguaraider.com