A “Squeeze and Heat” Approach to Water Reclamation

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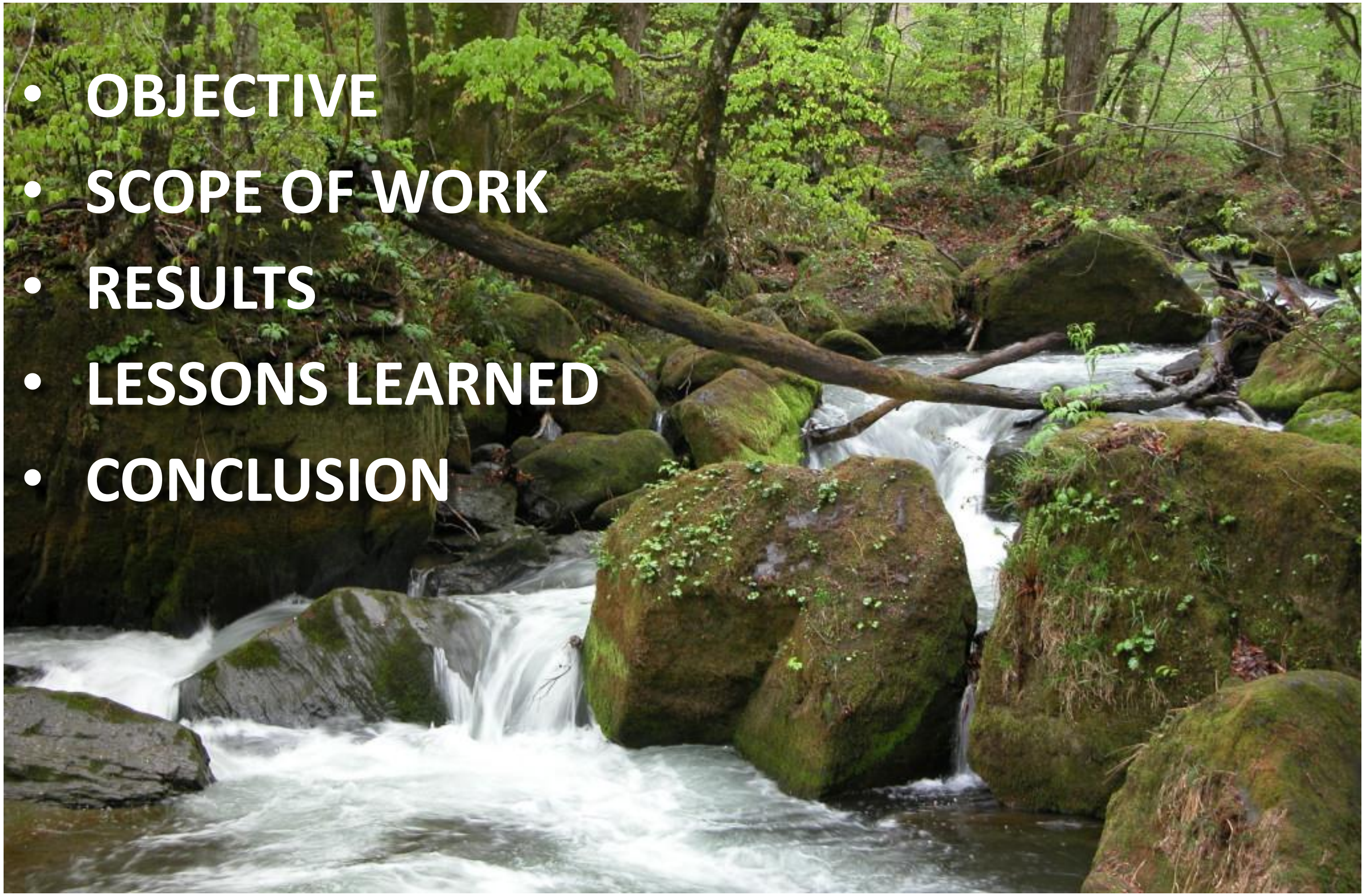
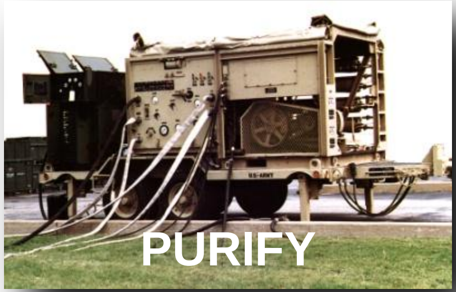
Presentation Agenda



- OBJECTIVE
- SCOPE OF WORK
- RESULTS
- LESSONS LEARNED
- CONCLUSION

The Water Cycle

STEP 1



STEP 2

STEP 3

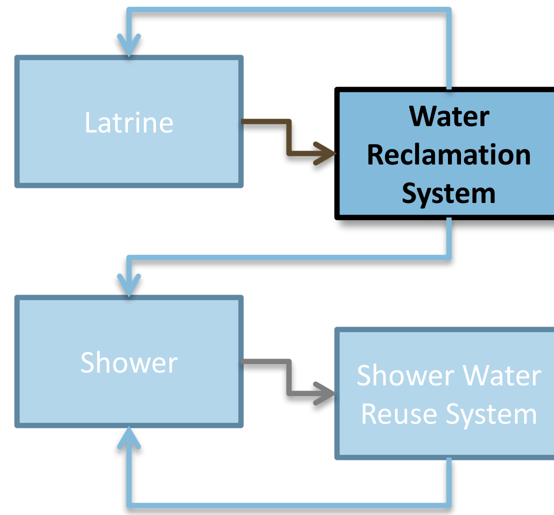
STEP 4

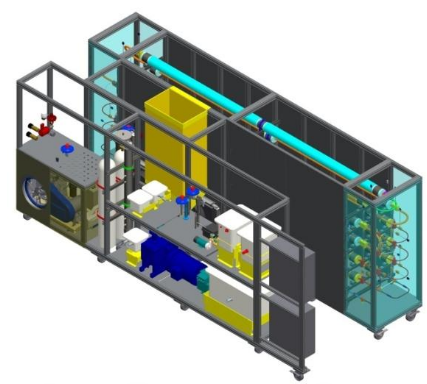
STEP 5


OBJECTIVE

Objective of the Effort

- Develop a system for producing reusable water from blackwater.
- Complement existing shower water reclamation system.
- Use the *change* in the *properties* of water that takes place when water is at high pressure and high temperature…
  - to *precipitate* inorganic material, and
  - to *oxidize* organic material.





Water Reclamation System


SCOPE OF WORK

Scope of Work

- Identify the end-user operational requirements.
- Research current and prior art in supercritical water oxidation.
- Perform tradeoff studies to select a process flow suitable for implementation.
- Select equipment for the chosen process flow.
- Build and test a process demonstration prototype.

Reusable Water Requirement

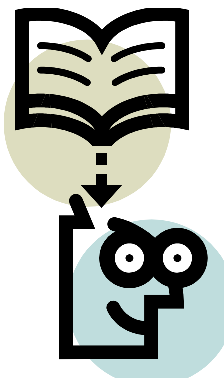
- Water quality criteria defined by the Department of the Army, Office of the Surgeon General.

Parameter	Max. Level or Range	Unit
Physical Properties		
Color	50	TCU
Odor	3	TON
pH	5 - 9	pH
Total dissolved solids (TDS)	2000	mg/L
Turbidity	1	NTU
Microbiological		
BOD5	10	mg/L
Coliform	0	CFU/100 mL

- Based on TB MED 577, Sanitary Control and Surveillance of Field Water Supplies, Dec 2005.

Technical Literature Search

- Sources consulted on supercritical water oxidation and blackwater chemistry…
  - Chemical Engineering Research and Design
  - The Journal of Supercritical Fluids
  - Chemical Engineering Journal
  - High Pressure Research
  - Waste Management & Research
  - Industrial & Engineering Chemical Research
  - Journal of Hazardous Materials
  - Water Science and Technology
  - American Institute of Chemical Engineers Journal
  - Society of Automotive Engineers
  - United States Patent and Trademark Office



Tradeoff Studies

- Tradeoff analyses were conducted in regard to…
  - Process flowsheet selection (TOPSIS)
  - Process control hardware selection (MUA)
  - Pressure controller hardware selection (Pugh Matrix)
  - Reactor kinetic models
  - Process equipment design

PUGH EVALUATION MATRIX

EWRS Pressure Controller

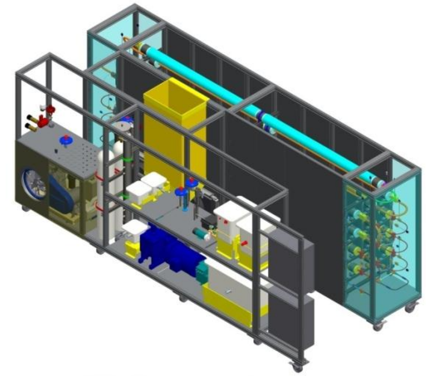
		Alternative Concept									
Category	Evaluation Criteria	1	2	3	4	5	6	7	8	9	10
	Input signal	0	0	0	0	0					
Signal	Output signal	0	0	0	0	0					
	Supply voltage	-1	0	0	0	0					
Power											
	Mode	0	0	0	0	0					
Control	Sample rate	+1	+1	+1	+1	+1					
	Operating	0	+1	-1	+1	-1					
Temperature	Storage	0	+1	0	+1	0					
	RS-485	0	+1	0	+1	0					
Communications	Protocol	0	0	0	0	0					
	Risk										
	Σ+	1	4	1	4	1	0	0	0	0	0
	Σ-	1	0	1	0	1	0	0	0	0	0
	ΣS	7	5	7	5	7	0	0	0	0	0

Pugh Matrix for Pressure Controller

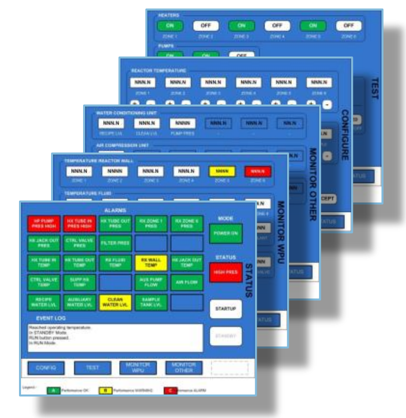
Acronyms:
- TOPSIS – Technique for Order Preference by Similarity to Ideal Solution
- MUA – Multi-attribute Utility Analysis

Design Tools

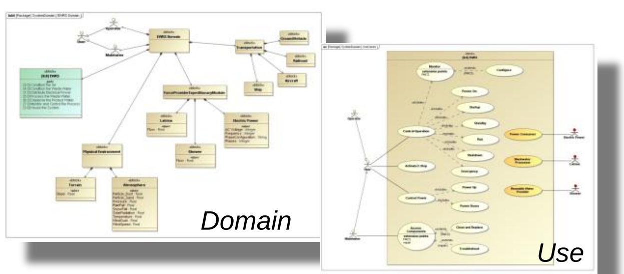
- System design tools used…
  - Chemical process simulation, CHEMCAD.
  - Heat transfer studies conducted using empirical correlations from literature search.
  - Insulation sizing, 3E Plus.
  - Mechanical component design and human factors analysis, Creo Elements/Pro (formerly Pro/Engineer).
  - Systems engineering, DOORS and MagicDraw.



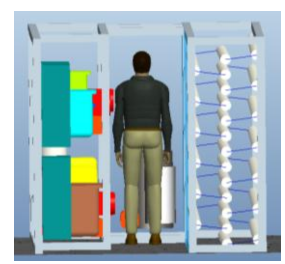
3D System Modeling



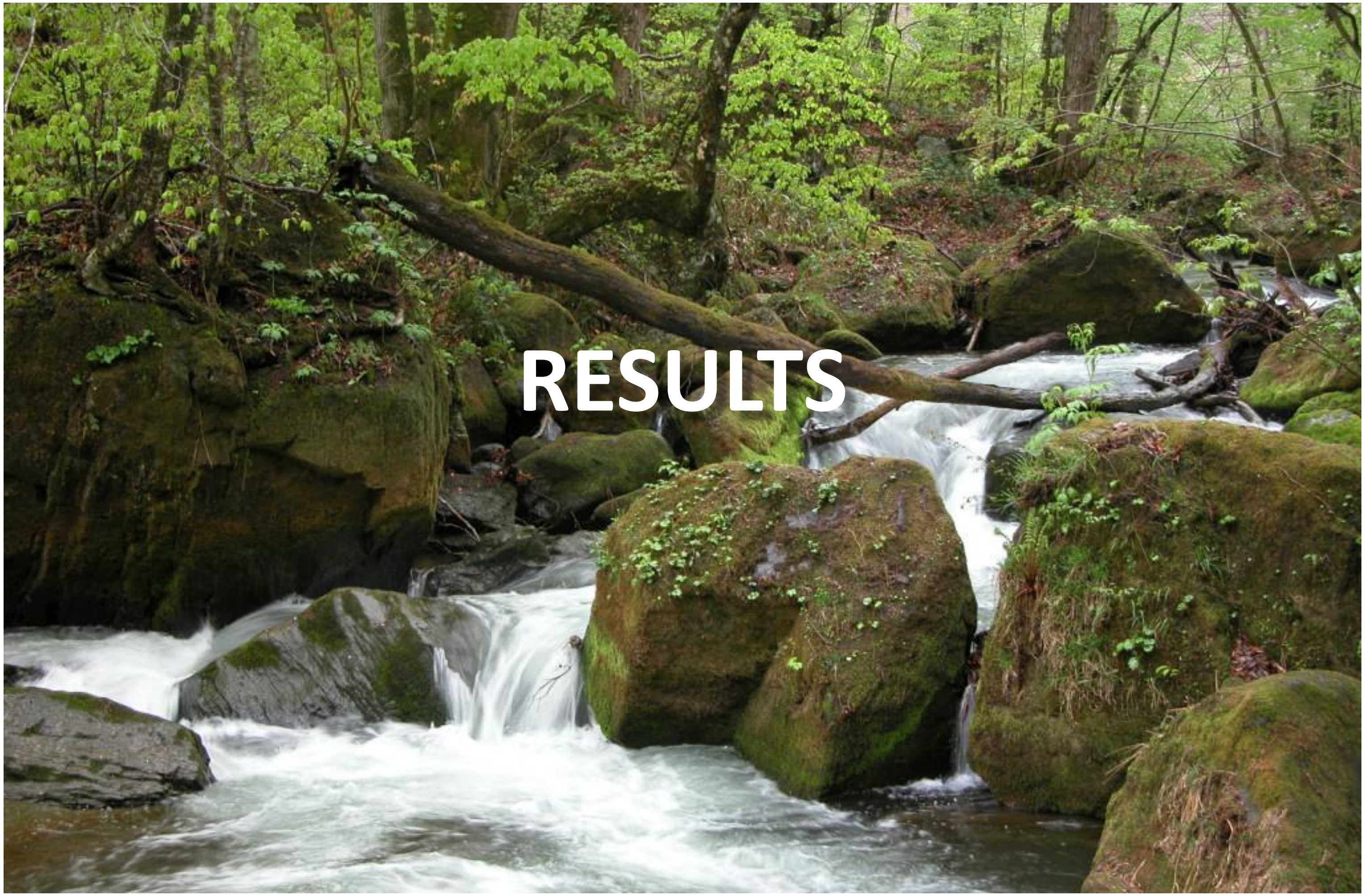
HMI Design



Functional Analysis and Design

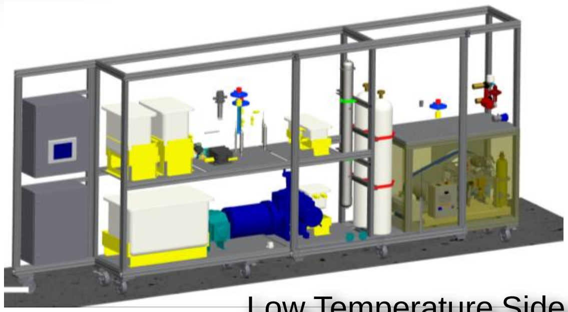


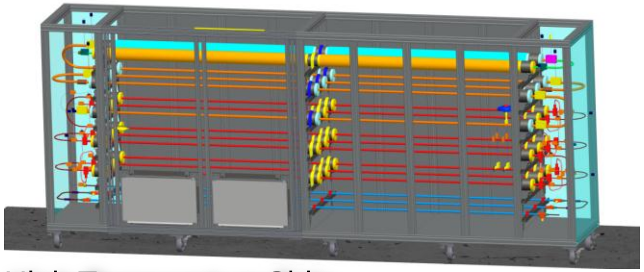
Human Factors Verification

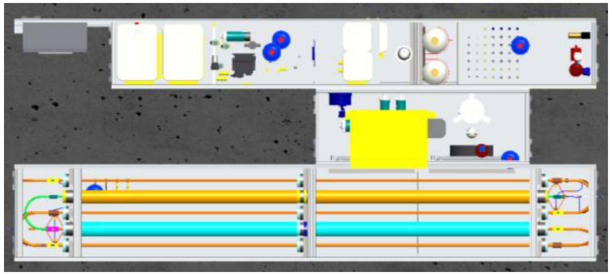

RESULTS

Results Summary

- The design of a 15 gph water reclamation unit has been completed.
- A recipe for artificial blackwater has been defined for use during test and evaluation.
- A design of experiments (DOE) has been established.
- The measures of process effectiveness have been identified.

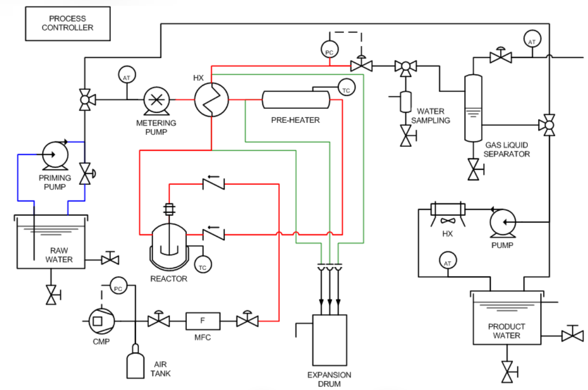

Low Temperature Side


High Temperature Side


Top View

Results - System Design

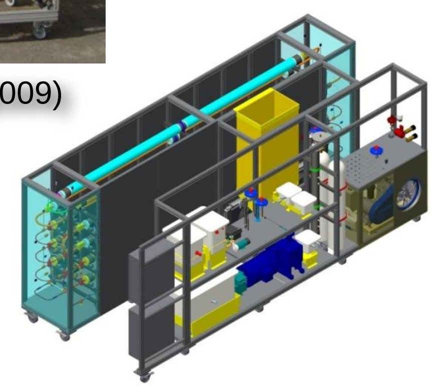
- Based on past design experience and recent technical literature.
- Comprises…
  - Power distribution,
  - Process control,
  - Water and air feed control,
  - Heat exchangers and reactor, and
  - Product water management.
- Fits in a 1C ISO container.



Process Flow


Prior Design (2009)

ISO Container form-fit


Present Day Design (2012)

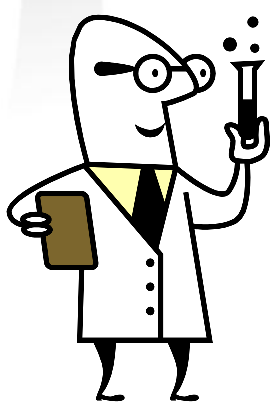
Results - Chemical Process

- Material balance performed for artificial wastewater
- Energy balance used
  - CHEMCAD chemical process simulator for fluid thermal demand
  - 3E Plus Insulation thickness calculation for thermal losses
- Reactor design based on flow rate, input concentration, conversion, and kinetics
- Heat exchanger design for thermal recovery involved pinch point analysis
- Reaction may be self sustaining for high input solids concentrations

Results - Artificial Wastewater

- Chemically and organically similar to blackwater.
- It is a controlled variable during process evaluation.

Recipe Ingredients
Peptone
Meat Extract
Vegetable Extract
Urea
Cellulose powder
K_2HPO_4
NaCl
$CaCl_2\ 2H_2O$
$MgSO_4\ 7H_2O$



Totals/Overall	BW Range	Recipe	Units
Overall Heating Value	13,900 - 16,100	14,028	kJ/kg
Organic Heating Value	-	14,978	kJ/kg
P as P_2O_5	2.3 - 4.3	2.4	%
K as K_2O	1.8 - 3.0	3.0	%
Fiber	20 - 35	29	% dry weight
Urea	11.7 - 23.1	8.8	% solids
Nitrogen	8.8 - 11.4	9.3	% solids

Results - Design of Experiments

- A ½-fraction experiment with 5 factors, 2 levels, 3 trials.
- The control factors (inputs) are…
  - Process temperature,
  - Process pressure,
  - Stoichiometric air ratio,
  - Wastewater flow rate, and
  - Feedwater solids concentration.

- The response measurements (outputs) are…
  - Turbidity
  - pH
  - Total Dissolved Solids
  - Total Suspended Solids
  - Biological Oxygen Demand

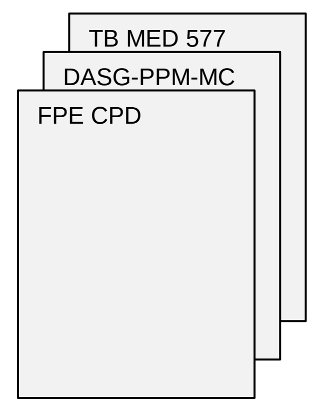
Results - Design Metrics

- Two sets of metrics used for evaluating the system design
- Measures of Effectiveness
  - A water production rate of 15 gph.
  - The reusable water quality criteria defined by the U.S. Army.
- Measures of Performance
  - Volume/footprint: 1C ISO Container
  - Weight: 10,000 lbs
  - Electrical Power: 30 kW


LESSONS LEARNED

Lessons - From End-User Perspective

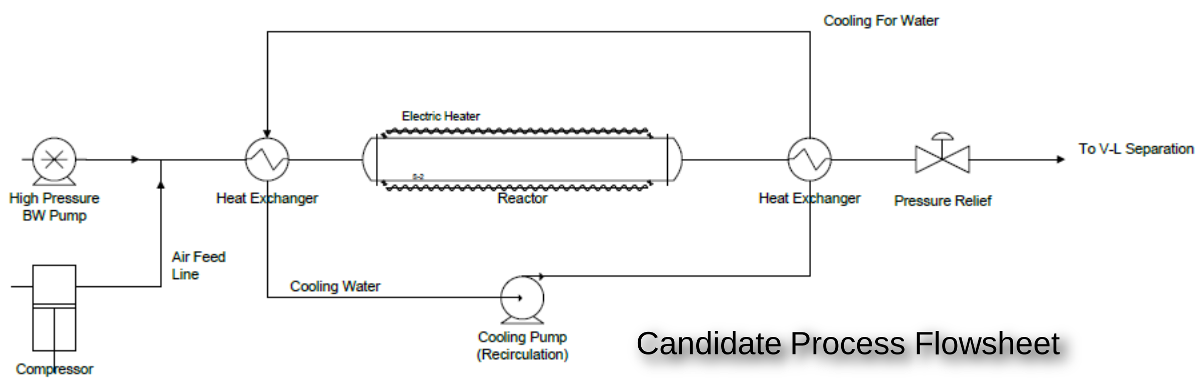
- Many potential field applications exist, both military and civilian.
- Force Provider Expeditionary (FPE) base camp selected for system and process evaluation.
- FPE has a need, but no solutions exist at this time.
- System reduces the water footprint.
- System reduces warfighter casualties.
- System increases base security.
- System reduces environmental harm.



End-User Requirements

Lessons - From Design Perspective

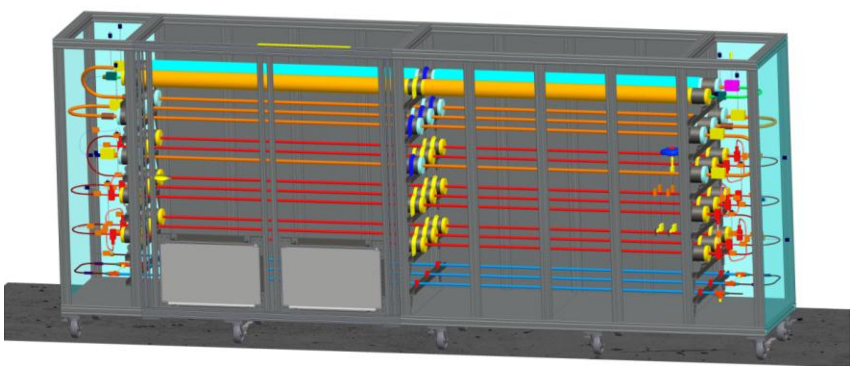
- The technical literature contains a wide range of empirical design criteria.
- The system design is based on conservative analysis.
- Some experimentation will be required, e.g. to quantify solids precipitation.
- Opportunities for reduced footprint and cost are anticipated.



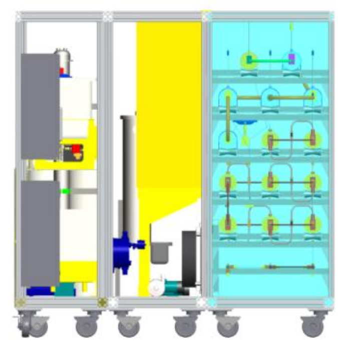
Candidate Process Flowsheet

Lessons - From Equipment Perspective

- Specialty metals are required, e.g. Hastelloy, Inconel, etc.
- Manufacturers qualified to design and build small-size pressure vessels are limited.
- Some large-size pressure vessel vendors are willing to go small-scale.



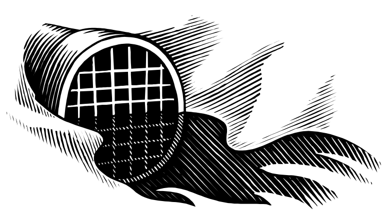
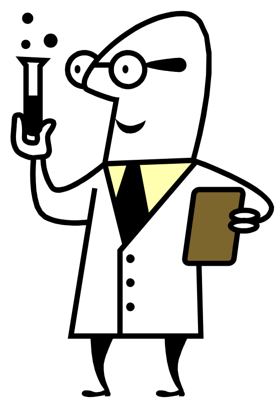
High Pressure and High Temperature Section



Side View

Lessons - From Process Evaluation Perspective

- There is no standard for evaluating wastewater treatment processes, especially energy and material balance.
- Had to develop an artificial wastewater recipe to emulate the chemical and organic composition of blackwater.
- There is only one set of criteria for reusable water, the one defined by the Department of the Army, Office of the Surgeon General.

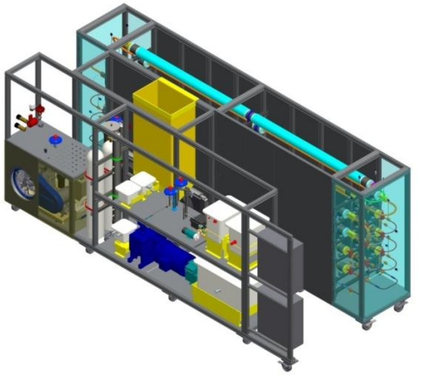





CONCLUSION

Conclusion

- The development of a water reclamation system has been presented.
- The effort is a joint industry-government endeavor.
- The resulting design offers great promise as a deployable, sustainable, in-situ, water reclamation system.
- A prototype is being built to quantify the process effectiveness and efficiency.



Blackwater Reclamation System

Future Work

- Evaluate alternative thermal energy sources, e.g. fuel fired heaters.
- Evaluate supplementary thermal energy conversion methods, e.g. Sterling engines.
- Evaluate alternative front-end processing methods to produce a higher solids concentration feed.
- Scale-up the design to higher flow rates, e.g. 50 gph.
- Ruggedize equipment for field test and evaluation.

Thank you!