TES Tanks

When Theoretical Design Parameters Meet the Real World

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Key Design Elements

1. Pressure drop is low
2. Tank must be insulated to minimize losses
3. Must ensure stratification
4. Must minimize thermocline
   - Low Froude Number
   - Laminar flow through diffuser slots

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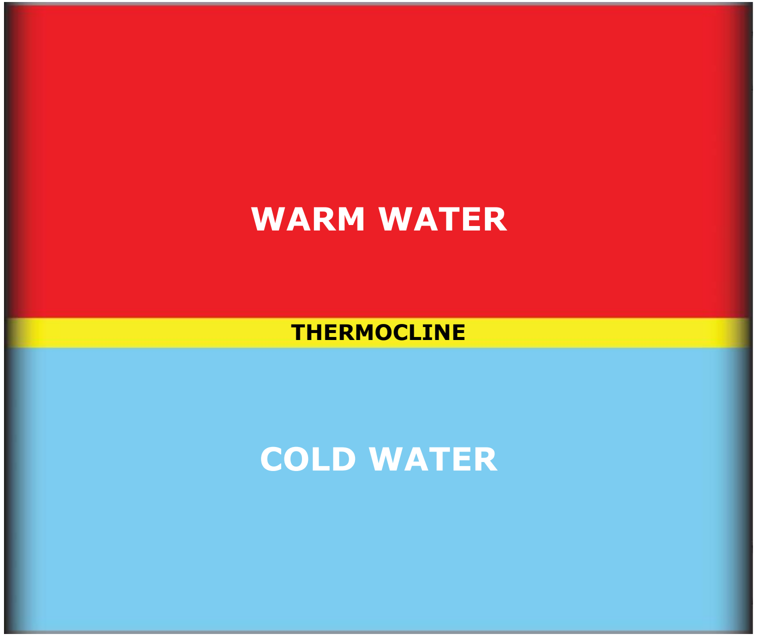
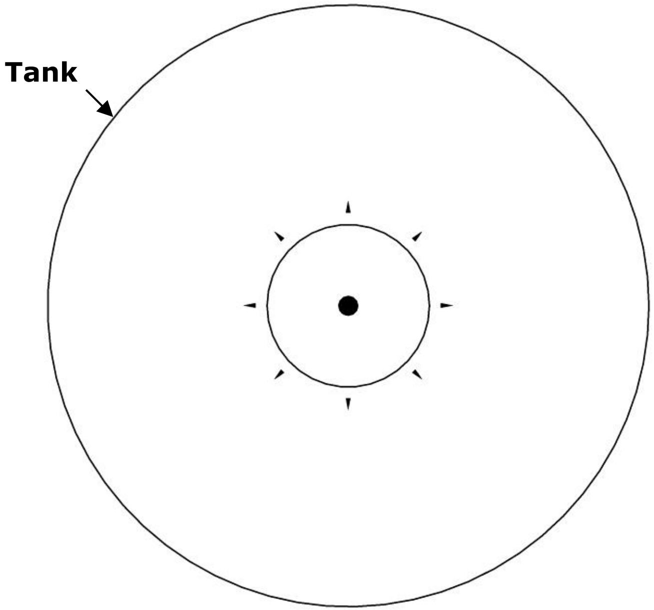
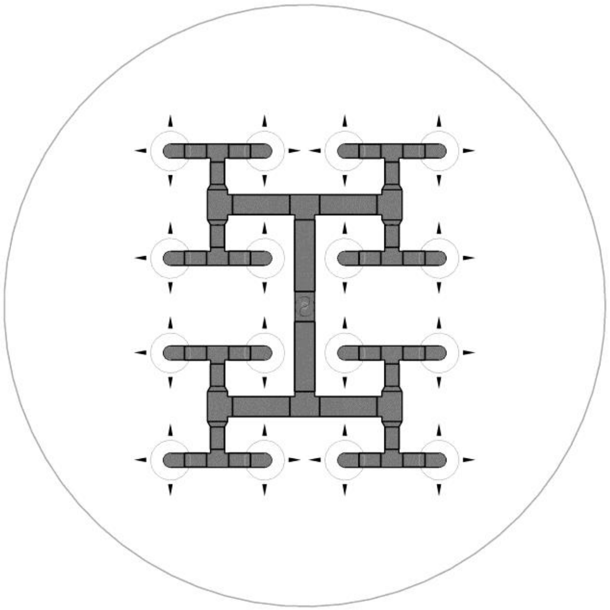
Thermal Storage Tank Stratification



Water Diffuser Systems

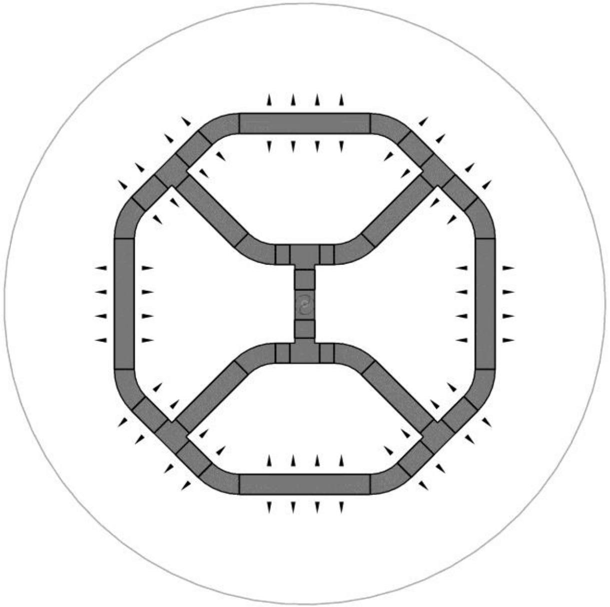


DISK

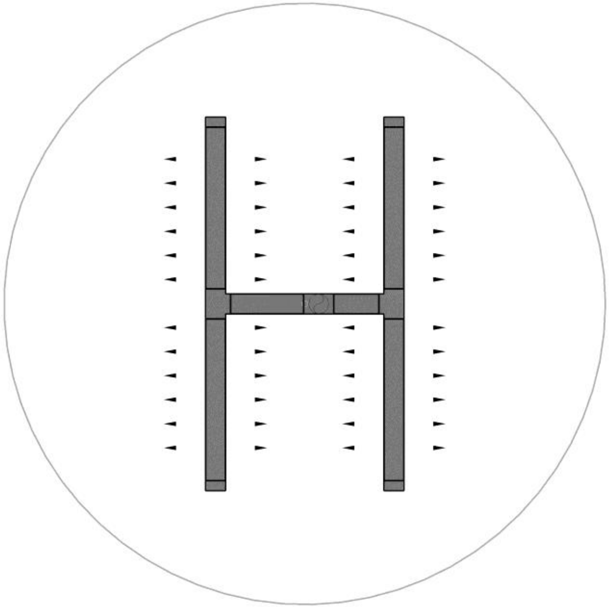


MULTIPLE DISK

Water Diffuser Systems

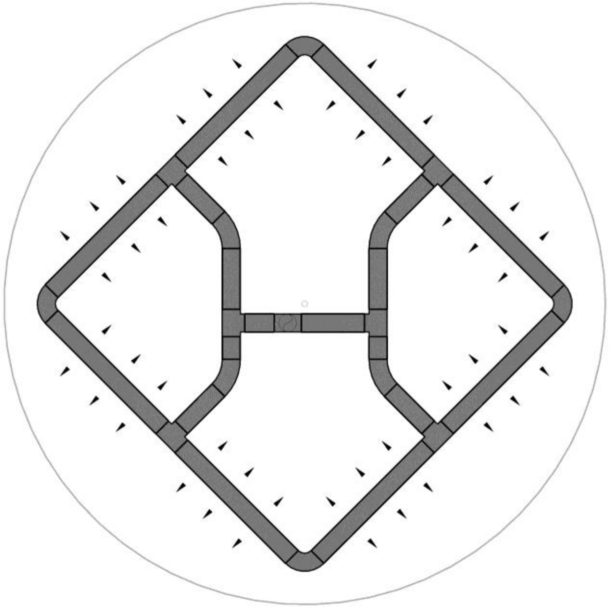


OCTAGON

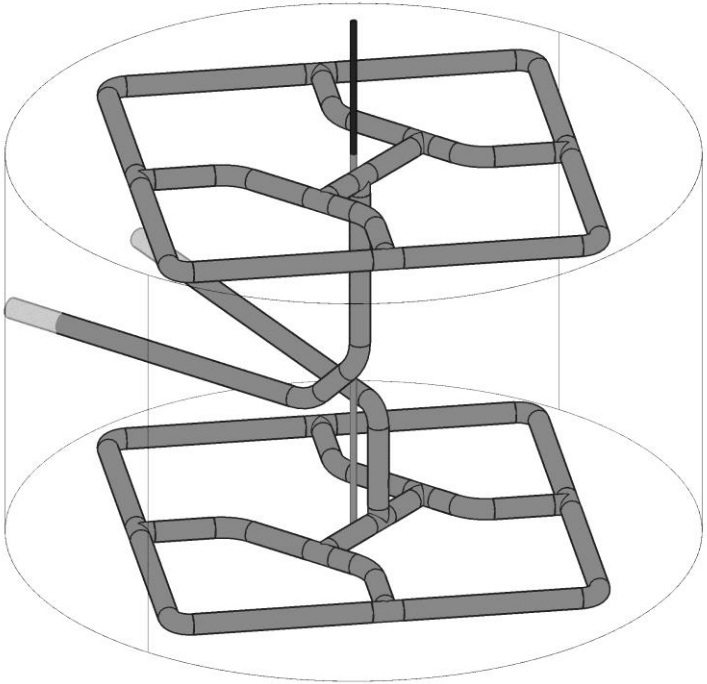


"H"

Water Diffuser Systems



SQUARE



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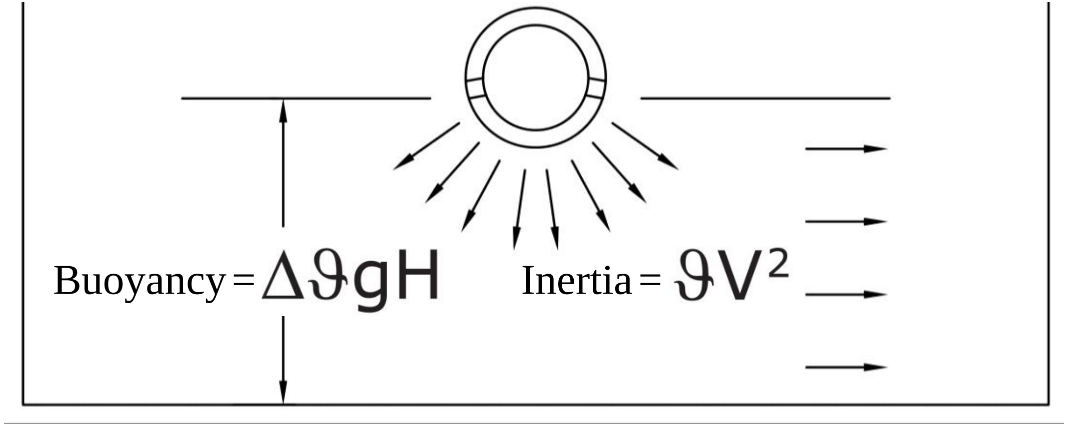
Froude Number

The Froude Number is the single most important design parameter in the design of the distribution system. It is the ratio of dynamic (inertial) forces to weight (buoyancy forces). A low Froude Number insures that the buoyancy forces predominate over inertia forces and allow the tank to be stratified.



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Froude Number

$$\frac{Q/L}{(gH^3 \times (\Delta\vartheta/\vartheta))^{1/2}}$$

Q/L = Volume flow rate per length of diffuser

g = Gravitational acceleration

H = Height of diffuser

$\Delta\vartheta$ = Difference in water density = $\beta(T_W - T_C)$

ϑ = Density of inlet water

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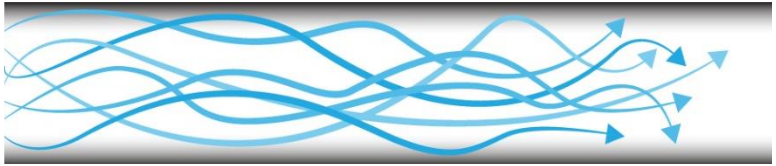
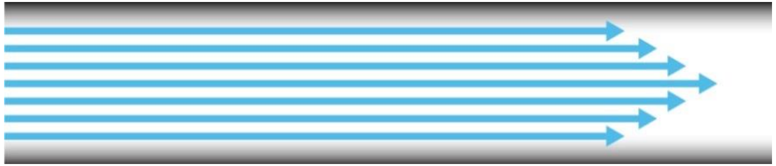
Reynolds Number

The Reynolds Number is the ratio of inertial forces to viscous forces. The critical Reynolds Number distinguishes between laminar or turbulent flow. A Reynolds number below 2000 is required to limit mixing action.



>2000



<2000

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Reynolds Number

$$\frac{Q/L}{\upsilon}$$

Q/L = Volume flow rate per unit length of diffuser

υ = Kinematic viscosity

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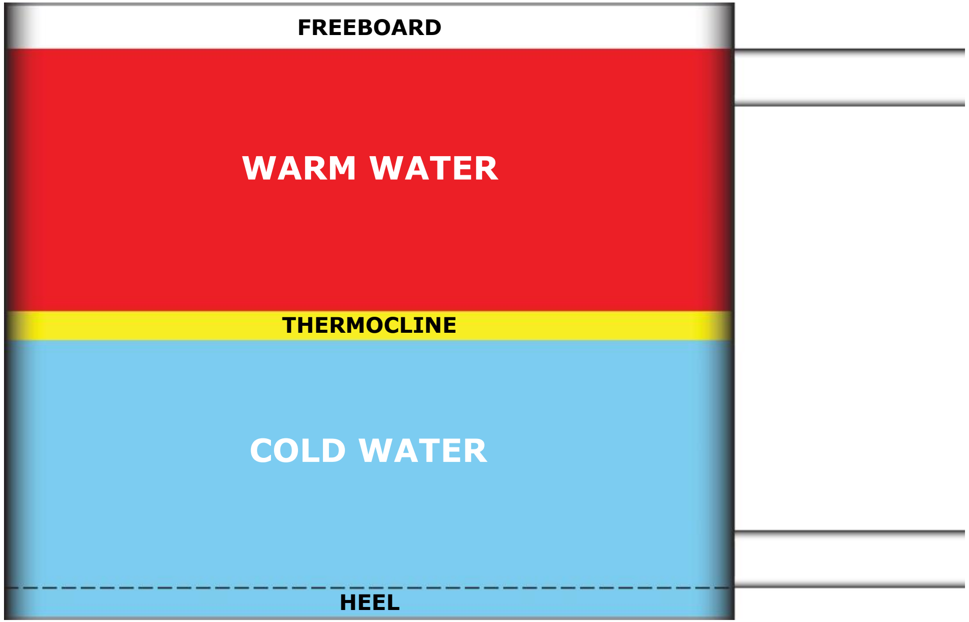
TES Capacity



Net Storage Capacity =
Total Capacity – (Freeboard + Thermocline + Heel)

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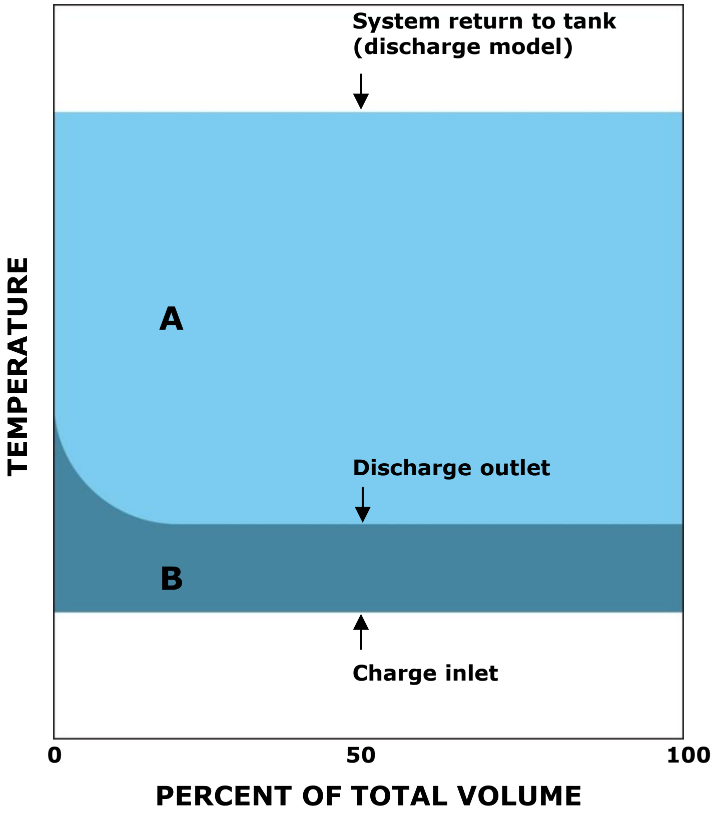
Figure of Merit (FOM)



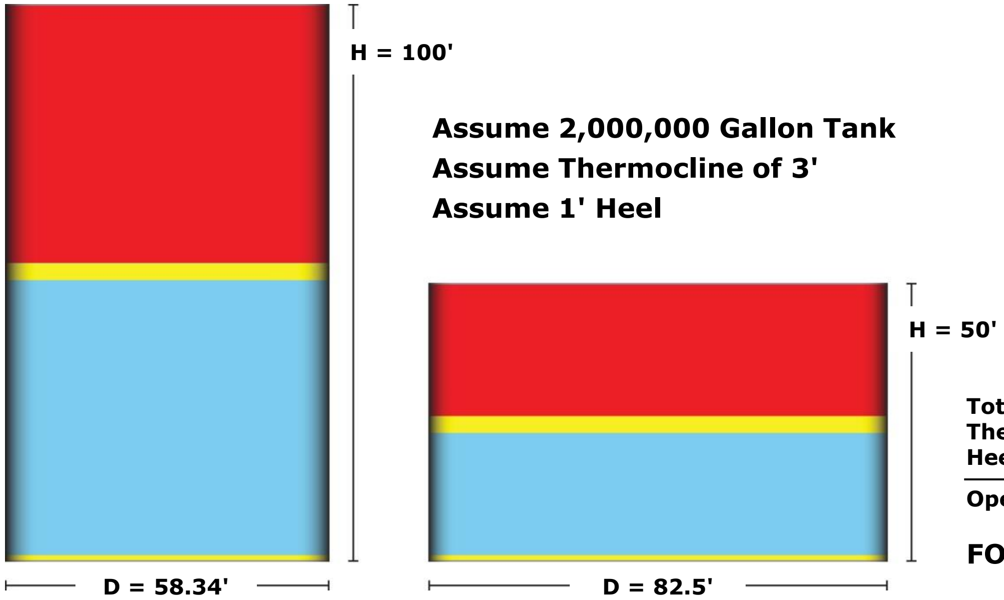
$$FOM = \frac{\text{Area A}}{\text{Area A} + \text{Area B}}$$

A = Usable volume

B = Unusable volume

A+B = Total volume

Tank Sizing: Effect of Tank Height to Diameter Ratio to Thermocline



Assume 2,000,000 Gallon Tank
Assume Thermocline of 3'
Assume 1' Heel

Total............2,000,000 gallons
Thermocline......59,990 gallons
Heel..................19,997 gallons

Operating.....1,920,014 gallons

FOM = 96.00%

Total...............2,000,000 gallons
Thermocline......119,964 gallons
Heel....................39,988 gallons

Operating.......1,840,048 gallons

FOM = 92.00%

Other factors concerning tank height to diameter:
Site Foot Print (available space), Foundation considerations,
Seismic, Tank economics, Insulation

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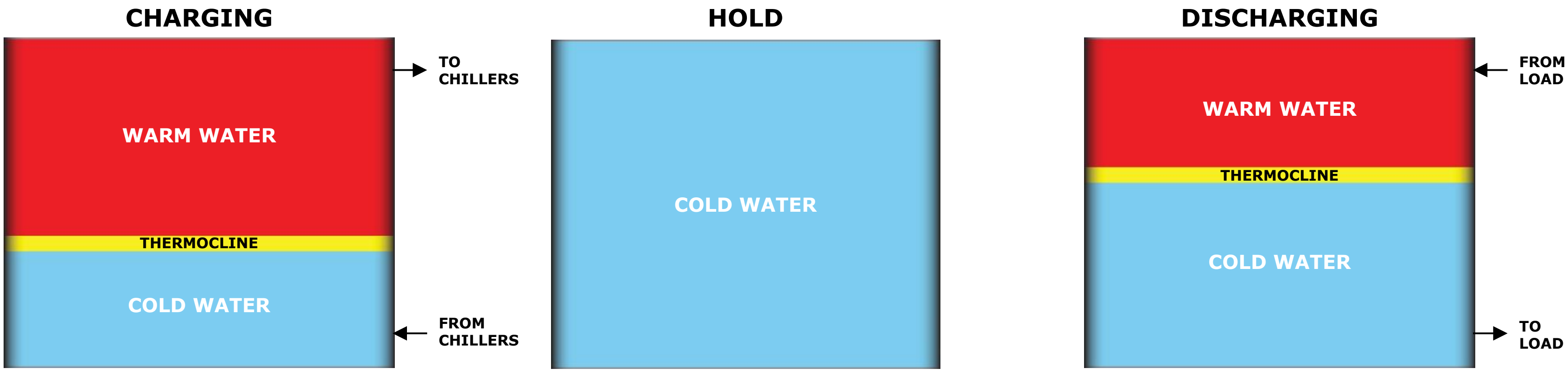
Performance Test



During the Charging and Discharging, measure the following every 15 minutes:

- Flow Rate In
- Flow Rate Out
- Temperature of water going in
- Temperature of water going out
- Temperature at regular height intervals
- Pressure at inlet
- Pressure at outlet
- Ambient air temperature

Abu Dhabi Results

Location	Abu Dhabi UAE
Owner	ABU DHABI Industrial City
General Contractor	Drake and Skull
Tank Contractor	Petron
Diffuser Type	TKDA H Shape- Slotted Pipe

			Results		
			Average	Min	Max
Parameter	Units	Design	Actual	Actual	Actual
Capacity	Ton Hours	**15,000**			
Peak Charge Rate	gpm	**4,486**	4380	4320	4426
Peak Discharge Charge Rate	gpm	**4,486**	3602	2792	5249
Chilled Water Supply	Deg. F	**40**	41.52	40.46	47.16
Warm Water Returned	Deg. F	**56**	44.65	44.19	46.22
Temperature Differential	Deg. F	**16**	2.46	0.72	4.28
Maximum Heat Gain	% in 24 Hours	**1.0%**	1.44		
Ambient Outside Temp	Deg. F	**131**	115		
Maximum Head Loss	psi	**3**	1		
Tank Diameter	ft	**72.18**			
Tank Height	ft	**49.22**			
Height to Overflow	ft	**48.72**			
Capacity	Gallons	**1,506,374**			
FOM	Percent	**90.00%**			

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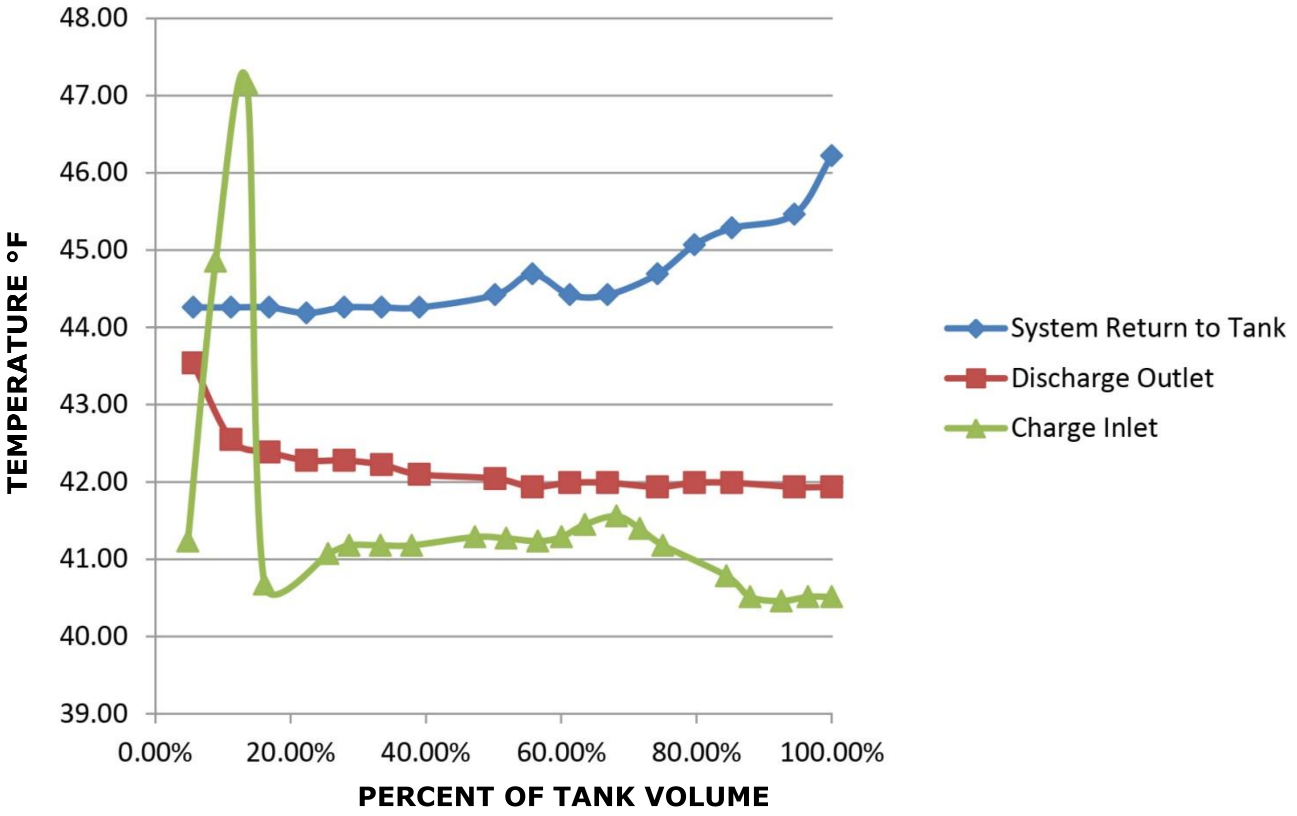
Abu Dhabi Graph

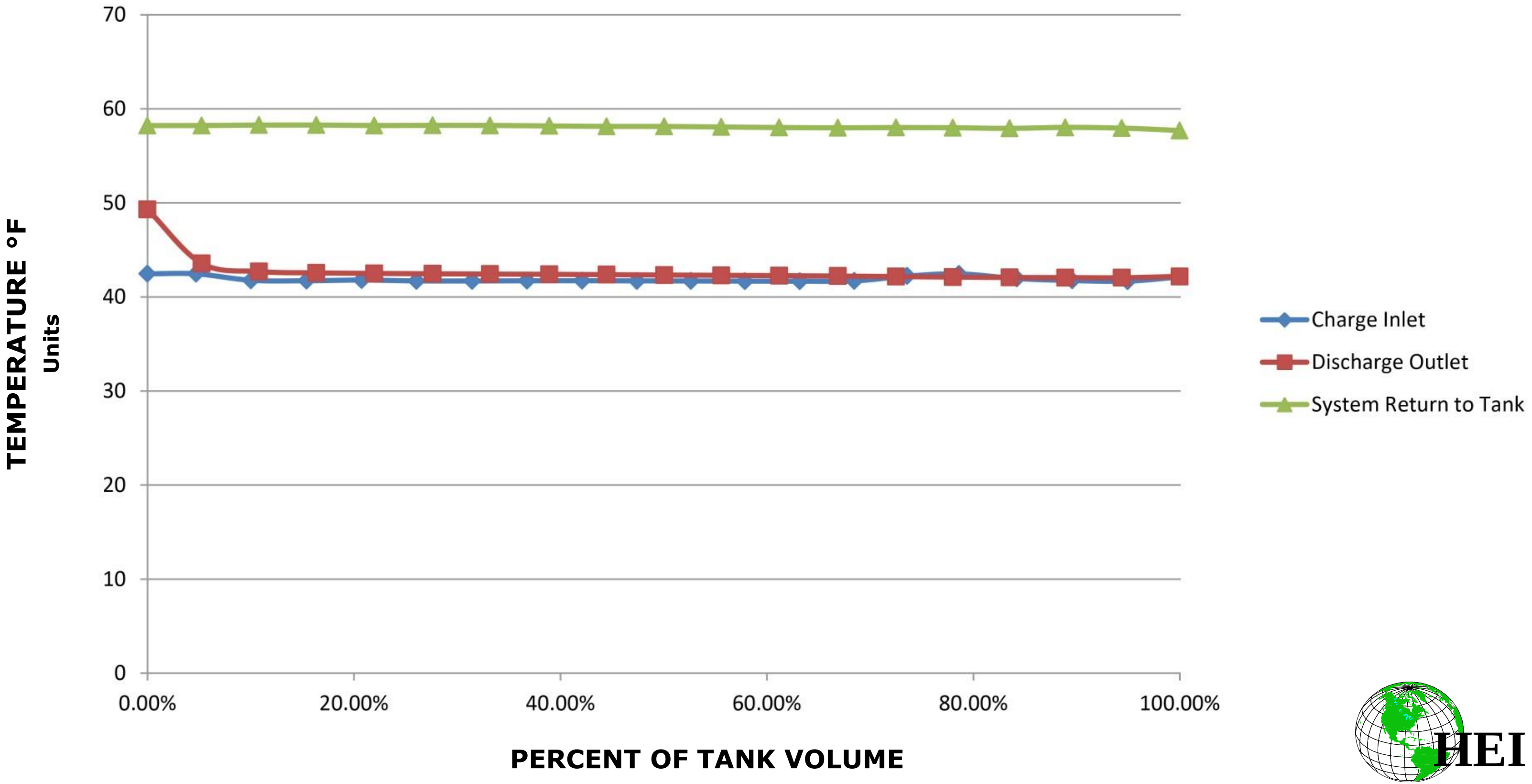


Stanford TES 2011 Results

Location	Stanford, CA
Owner	Stanford University
General Contractor	Whiting Turner
Tank Contractor	Pacific Tank and Construction
Diffuser Type	TKDA Patented Polygonal (square)

			Results		
			Average	Min	Max
Parameter	Units	Design	Actual	Actual	Actual
Capacity	Ton Hours	**45,000**			
Peak Charge Rate	gpm	**14,198**	14,016	13,185	15,458
Peak Discharge Charge Rate	gpm	**14,198**	14,252	13,280	14,684
Chilled Water Supply	Deg. F	**42**	41.85	41.67	42.45
Warm Water Returned	Deg. F	**58**	58.09	57.69	58.27
Temperature Differential	Deg. F	**16**	15.71	14.66	15.97
Maximum Heat Gain	% in 24 Hours	**2.0%**	0.00%		
Ambient Outside Temp	Deg. F	**100**	65		
Maximum Head Loss	psi	**3**	0.79		
Tank Diameter	ft	**100**			
Tank Height	ft	**82.5**			
Height to Overflow	ft	**75**			
Capacity	Gallons	4,399,739			
FOM	Percent	**92.00%**			

Stanford TES 2011 Graph



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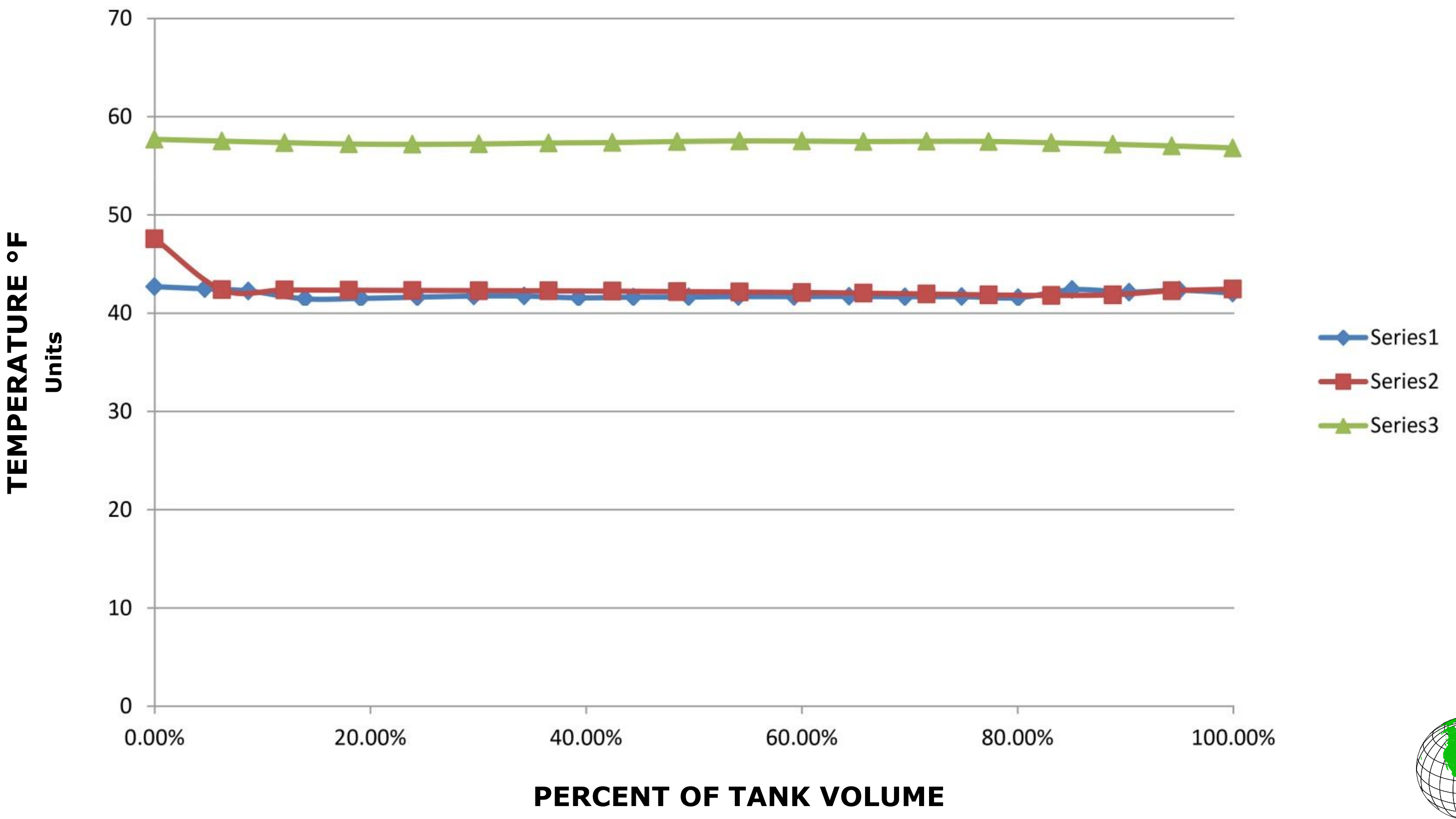
Stanford TES 2012 Graph



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