REALICE
Technical Comments and Questions
Where Do the Savings Come From?

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Sustainable Savings: Water-Energy Nexus

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I. BACKGROUND

This report is intended to provide responses to potential questions regarding the basis for REALICE energy savings and outline how the use of a simplified spreadsheet analysis tool supports those savings assumptions for Ice Rinks end use.

Use of Simplified Methods

The original basis for savings for the current spread sheet tool is based on Southern California Edison Emerging Technology Assessment[1] and then applied to a generic approach for other installations. It has been refined since the original version based on other REALICE installations and comments from both US and Canadian utilities. Use of simplified methods to determine energy savings to arrive at a reasonable incentive amount, is preferred to help reduce customer adoption barriers associated with full modeling and detailed Measurement and Verification (M & V) of projects. It is intended to reduce the time and cost that could make the technology too costly for customer adoption. It is well known that one key entry barrier for customers to adopt efficient technologies is if there is a lengthy and costly incentive process. This often defeats the intent of offering the incentive, especially for newer technologies.

We do understand that use of any simplified method will not replace detailed modeling, full or partial M & V on a project by project basis, but does offer a means to apply rebate assessments and customer savings assessments on a conservative basis for economic determination for some measures. The simplified method used for this technology involves specific input by the customer for key variables. In addition, this model makes several assumptions that produce "average" but conservative results that make it applicable for this approach.

INCENTIVES

Incentives from US and Canadian utilities have been provided for REALICE over the past few years based on the approach we have provided, i.e., modeled MS Excel tool. The REALICE efficiency measure could be considered a 'hybrid' measure as it is not currently positioned either as 'deemed savings" or as a full custom measure with pre and post M&V, as the calculation tool used to estimate savings is conservative in its assumptions and has its origins in prior M&V efforts. Here is a partial list of utilities offering incentives:

[1] ET09SCE0070 Ice Rink Water Treatment System_Final.pdf

II. BASIS FOR SAVINGS

The standard practice for ice rinks is to heat the water for ice resurfacing to high temperatures typically from 130-160°F. Typical commercial rinks will resurface the ice from 8 -12 times per day and some as high 20 times. That is a lot of hot water, that is no longer needed if this technology is utitlized. Ice makers historically use hot water because it reduces the micro air bubbles[2] that are inherent in water and when frozen cause brittle or cloudy ice. Heated water removes micro-bubbles and lowers the viscosity of the water, meaning that it flows more easily and transfers heat better as stated in the ASHRAE Refrigeration Manual[3].

The hot water is added to the ice resurfacing machine and then used for resurfacing the ice rink, a process that is repeated many times each day. Since the resurfacing machines have a capacity of anywhere from 150-200 gallons of water, an enormous amount of energy is needed to heat thousands of gallons of water each day. A typical commercial single pad rink can use over 500,000 gallons per year / per pad of ice.

A Sustainable Option

Because REALICE removes the micro air bubbles from the water based on fluid dynamics, heating the water to get hard clear ice no longer needs to be done resulting in lower energy use to heat the water and less load on the refrigeration system. The refrigeration brine temperature set point standard practice is to set a baseline temperature of from 14-20°F (before REALICE installation). Because the REALICE-treated cold water freezes much faster, the brine temperature must be increased from 4-5°F which results in energy savings. This increase is required because ambient city water, typically from 45F-60F will freeze to fast leaving lines in the ice while resurfacing and a too cold a brine temp creates very brittle ice lowing overall ice quality. Additionally, there are energy savings resulting from needing less energy to freeze cold water vs freezing hot water for each resurfacing.

The brine temp reset should be considered a persistent energy measure because for this application ice is the product of the ice arena operators and is analogous to a process load. The "formula" for high quality ice requires a consistent change in brine temp given that the incoming water is no longer heated.

Three sources of savings:

- ✓ Not heating water to 130-160°F (typically therm savings if natural gas heating is used)
- ✓ Resetting brine temperature control set point upwards 4-5°F (kWh savings)
- ✓ Freezing un-heated water vs hot water (kWh savings)

Here are some of potential topics for questions that will be addressed in this summary:

- Basis for chiller size in tons
- Assumed chiller efficiency (kW/ton)
- Chiller Load Factor
- The % savings per degree of brine temp reset

[2] A more detailed description of the technology effects is offered in Appendix I

[3] ASHRAE Refrigeration Manual 2010 'Hot water gives harder ice because air bubbles are removed and 'Water quality affects energy consumption and ice quality. Water contaminants, such as minerals, organic matter, and dissolved air, can affect both the freezing temperature and the ice thickness necessary to provide satisfactory ice conditions.' (ASHRAE Journal – Ice Rinks)

A. Assumptions and Inputs for Calculating Savings

Given the results of the many assessments we provide a simplified tool to "estimate" the savings for use of the REALICE system without having to do a full Measurement & Verification at each facility. The cost to perform M&V and all necessary monitoring and review for all installations would clearly make it cost prohibitive for end users to have the system installed.

To develop the model savings estimating tool the following two tables are used as the base inputs:
Example Inputs:

Number of rinks	2	Select the number of ice rinks or Pads at this location. Maximum = 3.
Number of REALice units needed (fill stations)	1	Select the number of REALice units needed for this arena
Type of water heater used in this facility	Tank	Select either tank or tankless from drop down list
Type of fuel used for the water heater	Gas	Select either gas, electric or heat reclaim from drop down list
Condensing/Non-Condensing	Condensing	Select Condensing or Non-Condensing from list -- If unknown use "Condensing"
Optional Financing Term (2-5 Years)	2	Financing is available as a purchasing option
Will you replace water heater with new tankless type?	No	To maximize the savings, it is best to replace the existing water heater with a tankless new water heater.

The first section has customer inputs that are required for the calculations. First the number of ice rinks or pads is used with further input (size of pad) to determine the cooling load requirements. Second, the number of fill stations is used to determine the number of REALICE units required. The type of water heating used (gas, electric, reclaim) is set. The inputs here are from drop-down lists and used to determine some of the requirements for ice resurfacing and resulting savings. The financing input is for cash flow, and the final input regarding tankless replacement is used to increase the overall efficiency of the facility post retrofit.

Rink size	NHL	NHL	Select the size of each rink -- NHL, MED or Olympic. Medd is 12,000 sq. ft.
Type of usage for rink	Sports	Sports	Default value used should always equal "Sports"
Number of days/week the rink is in operation	7	7	The average number of days per week the ice rink is operated
Number of resurfaces per day	8	8	Average number of times per day the rink is resurfaced
Number of shutdown weeks per year	-	8	Number of shutdown weeks per year
Capacity of resurfacing machine in gallons	200	200	Tank capacity of 150, 175 and 200 gallons. Only 85% (or less) of that amount will be used in the calculations.
Incoming cold water temperature (°F)	55	55	Incoming (city, well or heat reclaim) water temperature. Default temperature is 60°F
Current resurfacing water temperature (°F)	140	140	How high is the resurfacing water heated to currently? The default temperature is 140°F.
Chiller Plant type	Ammonia	Ammonia	Ammonia or CFC
Age of Chiller Plant	>15	>15	Approximate age of the chiller plant (or facility) Note: for Duke derating set to 0%
Electric Utility	OG&E	OG&E	Name of electricity supplier
Average Blended Electric Utility Rate ($/kWh)	$ 0.080	$ 0.080	If the electricity rate is unknown, leave it blank and it will default to an average for the area
Gas Utility	Mustang Gas	Mustang Gas	Name of Natural Gas or propane supplier
Gas rate ($/Therm)	$ 0.300	$ 0.300	If the gas rate is unknown, leave it blank and it will default to an average for the area

In this section, there are several more customer inputs that are used in the calculations. First the Rink Size selection (drop down list) determines the square footage used for the cooling load calculation. The type of usage determines the chiller size the approximate tons per square foot required[4]. Typically, the facility operators do not know the actual tonnage of the refrigeration chillers so we use the conservative ASHRAE values.

The number of days a week, the number of resurfaces per day and the number of shutdowns annually are used to determine a couple of items. Of importance to electric savings, is the baseline use of cooling plant energy to "freeze" the hot water used for resurfacing. Once the hot water is applied to the surface of the ice rink, the cooling system must freeze that layer of water to the current or set ice conditions. This energy is calculated using the difference in temperature with the plant efficiency.

[4] ASHRAE 1994 Handbook Chapter 33

The age of the chiller plant is important especially if the analysis is trying to calibrate to some type of utility data. As all are aware, as a plant ages it does not maintain “new” plant efficiency. The default efficiency of the plant is set at 0.90 kW/Ton or sometimes to be more conservative 0.80 kW/Ton. As discussed in this report other study references show that this is a very conservative value. Also, this value appears to work well in calibrating to the estimated percentage of the total utility usage. There is an ability of a review party to modify this input and use it as a method of calibrating to the estimated total electric load of the plant as a percentage of the total utility billing *if known*. The 0.9 kW/Ton also is conservative based on the actual SCE study as well as the “estimated” calculation of efficiency discussed above in this report.

In July 2013, a study was published that covered twelve different types of cooling systems specific to ice rinks[5]. This study included different types of plants and did provide a COP (coefficient of performance) for each type of refrigerant system. The following table is a summary of the information from that study that is relevant to this discussion.

Study Results for Efficiency of Ice Rink Plants				
System Number	Type	Refrigerant	COP (cooling)	Efficiency (kW/Ton)
A1	Packaged	R717	2.4	1.47
A2	On site	R717	2.5	1.41
A3	On site	R717	2	1.76
A4	Packaged	R717	2.3	1.53
A5	Packaged	R717	2.1	1.67
C1	Split-packaged	R744	3.1	1.13
C2	Split-packaged	R744	2.6	1.35
H1	On site	R22	1.8	1.95
H2	Packaged	R507A	2	1.76
H3	Modular	R410A	1.7	2.07
H4	Modular	R507A	2	1.76
H5	Packaged	R134A	1.8	1.95
Average of All				1.65

Note that the values for the plants here are much higher (average **1.65 kW/ton**) than the input of 0.80 to 0.90 kW/ton used in the simplified US calculator. This study is just addressing overall plant efficiency. In another study that was recently completed by Rich Minneto[6] P.E. for an airport chilled water system the following information is provided:

GIAA – Central Plant 2016 Efficiency Summary Table					
Values	Chiller 1 and 2 ON	Chiller 1,2 and 3 On	Chiller 1,2 and 4 On	Chiller 1,3 and 4 On	Total Valid Hours
Average kW/Ton	0.746	0.896	0.968	0.958	
Hours	436	117	4	3	560
% Condition	77.86%	20.89%	0.71%	0.54%	
Annual Hours	6,821	1,831	63	45	8,760
Calculated Average Total Plant Efficiency kW/Ton (Annual Basis)					0.780 [7]

This facility contains all **NEW** high efficiency chillers, cooling towers, pumps, and associated equipment. One of the chillers is VFD controlled and all the pumps and cooling towers are on VFD’s. The system is controlled by a state of the art Johnson Controls system. Note that for a NEW plant the efficiency value is essentially within range of the initial value used for the typical ice rink refrigeration system.

The remaining two inputs are for rates if known to provide input on savings in dollar format and for use in financial analysis. If left blank values are filled from a look up table.

[5] Comparative Study of Refrigeration Systems for Ice Rinks; CanmetEnergy, Varnennes; July 2013
[6] Conducted the original SCE ET assessment on REALICE
[7] 2016 Energy Assessment Report; Antonio B Pat International Airport; November 2016

A. Calculations

This section deals with the calculation based on example rinks

Brine Temperature Increase and Freezing Colder Water - example

Brine Temperature Increase Savings Calculation

Description	Rink 1	Rink 2
Square footage of ice surface	17,000	17,000
Square ft/ton for usage type	140.0	140.0
Total tons of cooling	121.4	121.4
Type of chiller cooling	Ammonia	Ammonia
Starting KW/Tons	0.90	0.90
Glycol mixture %	30%	30%
Capacity de-rate for glycol	98.00%	98.00%
Stated plant age	>15	>15
De-rate factor for plant's age	15.0%	15.0%
Projected plant efficiency KW/Tons	1.06	1.06
Default plant load factor	55%	55%
Total ton hours of cooling	585,043	585,043
Total kWh baseline	617,877	617,877
Default Delta T for brine temp	4	4
% Savings from brine Delta T	9%	9%
kWh savings from brine temp Increase	55,609	55,609
$/Yr savings from brine temp Increase	**$4,449**	**$4,449**

A future version will show separate kW/ton for ammonia refrigerant.

The calculations in this section are straightforward and essentially based on input and some standard factors which are detailed herein.

- Square Footage – Calculated based on standards for ice rinks and the input from the above discussion on type of rink[8]. For a "medium" rink a smaller size was used. The following table is used for this input:

Rink Type	Sq. Ft
NHL	17000
OLY	19306
MED	12000

- Tons per square foot. Refer to footnote 4 and the ASHRAE standard for approximate tons required for Ice rink freezing.
- Total Tons of Cooling – a calculation using square footage and tons/square foot.
- Type of Cooling – Here the input can be CFC or Ammonia. Current values are the same until we have more results from other zero GWP testing in process.
- Plant Efficiency Selection – This value is based on either the state selection from the input or is based on the selection of CFC or Ammonia as the refrigerant. (not a variable currently)
- Stated Plant Age – This is used to de-rate the efficiency of the plant based on age.
- Default Plant Load Factor – The "default" value was based on the SCE ET study overall annual load factor based on service meter monitoring. Ideally existing customers should provide a minimum of one year's

[8] IIHF Rink Guide; IIHF Rink Standards; April 2016

worth of electric utility data and that as noted herein can be used to "calibrate" the model to ensure not only better accuracy but conservative outputs. The model allows input of an actual calculated load factor *where the data is available* or defaults to a set value based on typical rinks. We see factors from 50% to as high as 80% as reasonable.

- Total Ton Hours of Cooling – The calculation used the tons calculated and multiplied by the available hours as input by the customer. For example, if the customer indicated the rink was down for one week – the ton hours would be:

  Tons X (8760 – 168) = Ton Hours

- Baseline kWH – Multiplication of the ton hours by the kW/Ton to arrive at kWH. Again, with actual utility bills and the analysis herein this value can be and was "calibrated" using actual input information as detailed herein.
- Delta T modification – If the customer inputs a value the proposed value is used. If the customer does not input a value a 4 degree Delta T increase is assumed. Typical rinks can adjust from 3F – 5 F. Again, this will be site specific information and as noted herein the model was modified to default to a lower and more conservative estimate based on the rink information. Note: the customer *must reset the brine temp otherwise ice quality will suffer significantly.*
- % Savings with brine reset –The information used in the simplified model was based on a few considerations:
  - The SCE ET Study
  - Standard "rule of thumb" savings for chilled water reset using centrifugal chillers[9]. The following table is used for this savings estimate:

Delta T	% Energy Savings
1.00	2.10%
2.00	4.40%
3.00	6.75%
4.00	9.00%
5.00	11.25%

- The above table typically shows a minimum of 2 to 1 savings for chilled water reset. Another typically used value10 defaults to 1 to 2.5% savings for each degree of water reset. ET study showed that at 2 degrees the savings was 4.6% or a factor of 2.3% savings for each degree. The table for default values has been demonstrated to be in line with expected results from the SCE study and general standards for chilled water reset. Also, to be conservative the delta T can be modified to a default value of 3 Deg F where it is expected that most facilities will be able to reset to a higher value (4 - 5 Deg F).
- For the SCE study rink savings were verified at different brine temps. At a 2F delta on the brine temp change there was a 4.6% annual extrapolated energy savings. A value of 4.4% was used to be conservative. The brine temp reset was then set to a delta 4F for a period of time to determine a second value. The savings resulted a 9.8% value. However, the rink could not maintain this reset for an extended time period for reasons not related to REALICE. The table was a result of actual data collection for the ice rink in Oxnard CA.
- A detailed M&V study was conducted by Straradyne Group on an installed REALICE unit in 2018 by its certified energy auditor (P.E. CMVP). It demonstrated a 2F brine temp reset and measured ad 13% kWh savings on the rink refrigeration system and 289,600 kWh annually as compared to baseline.[11]

[9] Trane Trace User's Manual; Chilled Water Reset Chapter 5
[10] TRANE Trace 700 User's Manual Section 5-25
[11] Application 184,015 Iceland Mississauga Pre-project Evaluation

- A linear regression of compressor versus outside air provided a “linear” result but still had several outliers. Using some standard compressor curves provided some extrapolation and conservative input for the other values.
- From one degree to two – The standard shows a full linear increase. Since it was conservative in the measured 2 degree brine increase, we gave a factor of 2.1 to account for the initial 1 degree increase. For the other values we used standard compressor data to accommodate the adjustment. In the actual data we gathered, even with the fact that the Oxnard facility could not operate consistently at 4 degrees delta T – we actually saw numbers closer to twice the reported savings, so the table if anything is more conservative than the savings that should be realized.
- “*Each degree Fahrenheit that you raise the ice temperature reduces the load on the ice plant by up to 2%. The drop is because of the combined effects of conductive, convective and radiant heat loads on the surface*[12].”
- kWH Savings – Multiplication of the baseline kWH times the % savings.

The following table summarizes the electric savings by using cold water for resurfacing. This is the chiller energy **saved by freezing cold water vs having to freeze hot water.**

Ice Resurfacing Chiller Savings (Going from hot water down to 32°F)	117.0	117.0
	Rink 1	Rink 2
Total hot water saved in gallons/year	407,680	344,960
Delta T for water applied to ice which must be frozen	85.0	85.0
BTU required for water heating	289,004,352	244,542,144
Equivalent ton hours	24,084	20,379
Chiller plant kWh savings for resurfacing using city provided temp water	25,435	21,522

The energy savings in natural gas in using unheated city water – *example*

This is the water heater savings achieved by not having to heat the resurfacing water in the first place- use cold water.

- Resurfacing machine (Zamboni) capacity in gallons of hot water with the machine using only 85% (or other default) of the capacity for each resurfacing.
- Customer input for how many times the rinks are resurfaced per day
- The rinks are used 7 days per week and a shut-down period based on customer input.
- The supply water temperature used is 60°F – default used unless customer site input differs
- The current hot water temperature is 140°F – default used unless customer site input differs

[12] The Energy Management Manual for Arena & Rink Operators.pdf

Calculation of Total Quantity of Water Required for Resurfacing

	Rink 1	Rink 2
Description	**Units**	
Average resurfaces per day	8	8
Average use in days per week	7	7
Total weeks per year	52	52
Number of shutdown weeks each year	0	8
Gallons of water used for each resurfacing	140	140
Annual gallons of water needed for resurfacing	407,680	344,960
Average gallons of water used each day	1,116.93	945.10
Incoming cold water temperature	55	55
Heater output water temperature	140	140
MBTU/day usage	7.92	6.70
EF for selected water heater type	0.530	0.530
Water heater type	Gas	Gas
Natural Gas rate	$0.3000	$0.3000
Therm savings	5,458	4,618
Electricity rate	$0.0800	$0.0800
Electric savings kWh	-	-
Annual Savings with REALice	**$1,637**	**$1,385**

III. APPENDIX I: TECHNOLOGY DESCRIPTION

The patented Vortex Process Technology (VPT) causes a fluid[13] to organize into an ordered vortex movement within the unit, resulting from the elaborate 3D design of the vortex chamber. The unit must be 3D printed to achieve the proper design and is made from a dense polyamide food grade material.

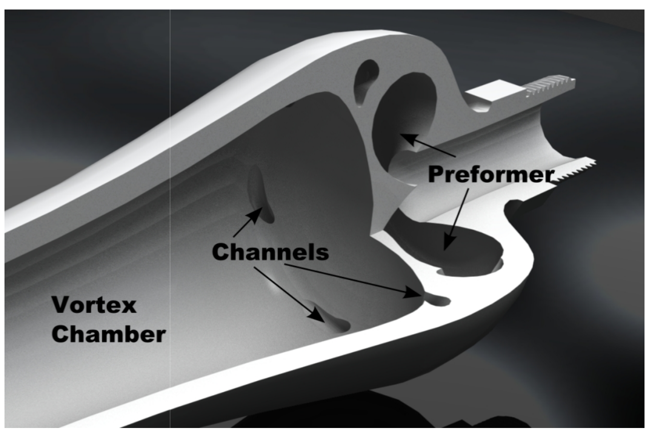
There are observed physical changes to the fluid resulting from the particular application:

EFFECTS OF THE VPT PROCESS ON NON-AERATION APPLICATIONS USING WATER

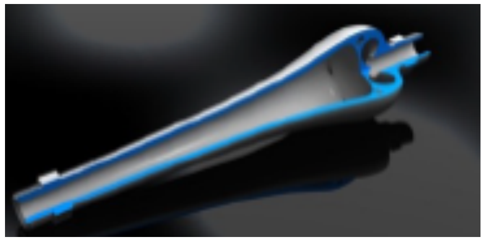
1. **Entrained micro-bubbles are stripped from the fluid flow**
2. **The viscosity of the resulting water is lowered**
3. **The heat transfer capabilities of the water increases, both in liquid and solid states**
4. **Dissolved calcium ions are precipitated into calcite and aragonite crystals in the water. These crystals do not solidify onto warm or collect on metal surfaces**
    1. **The into calcite and aragonite crystals act as seed crystal in the water to promote further removal of calcium carbonate as found chiller cooling tower systems.**

The energy for the process is derived from the pressure[14] of the incoming water with a recommended PSI of 43 or higher. At that pressure, the VPT generates a continual, well-defined vortex creating a powerful sub-pressure within the unit . The lowest pressure that has been measured in the unit is minus (-0.97) bar or approximately -0.957 atm (standard atmospheric pressure.) When the water is forced through the trumpet shaped vortex chamber (see Figure 1) its rotating speed increases as the radius of the trumpet becomes more and more narrow.

Figure 1 Vortex Chamber **of a REALICE unit**



[13] Water in the case of REALICE and VPT- Cooling Tower end uses
[14] For REALICE use the typical city water pressure of from 43 to 85 psi is sufficient. The VPT unit can withstand pressure to 1,500 psi

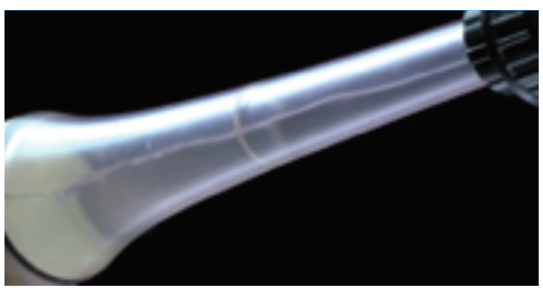


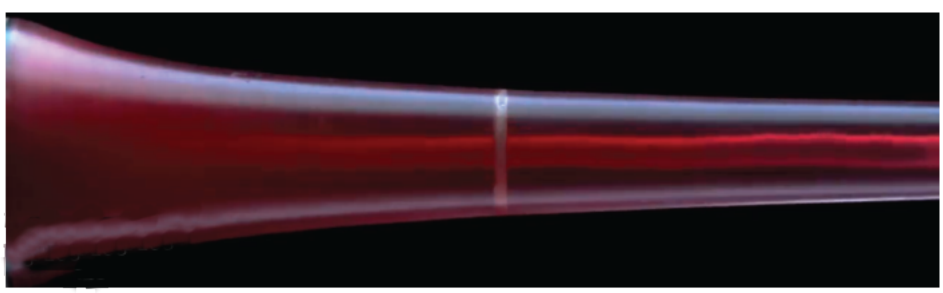
VPT Process

1. **Pre-former.** The inlet of the vortex generator provides a smooth outward direction of the flow through toroidal motion toward a set of well-defined channels.
2. **Channels.** After the pre-former, the fluid is directed through a set of channels, each with vortex-forming geometry. Each channel delivers a jet stream of vortex flow tangentially into a vortex chamber.
3. **Vortex chamber.** In the vortex chamber, the vortices from the channels are wound together. A strong and stable vortex flow is formed inside the vortex chamber, causing a strongly reduced pressure along the vortex axis. Depending on the application, the vortex chamber can have different shapes. A trumpet shape (Figure 2) produces a well-defined vortex with a smooth transition to downstream piping.

During this process, a large pressure gradient is generated inside the trumpet so that the pressure is at the lowest value in the center and the highest at the periphery of the vortex. The lowest pressure at the center extends for the length of the vortex, pulling the entrained micro air bubbles to the center of the vortex where they are gathered into a shape resembling an elongated tornadic volume of air with a very low pressure.

Figure 2 Removal of Micro-Bubbles





AIR IN WATER

Air, by definition, is a gas with typical ratios by volume: nitrogen (78%), oxygen (20%), argon (0.93%), carbon dioxide (0.04%), plus traces of neon, helium, methane, etc. The solubility of air in water depends on two factors: temperature and pressure. The solubility of air in water decreases as temperature increases.

Ice rink resurfacing water has historically been heated to remove the air from the water which gives better ice quality compared to ice that is made with water containing a higher volume of air. This process requires significant energy to heat the flood water and then significant energy to remove the heat from the water in order to freeze it – a process required several times per day. For example, at 14.7 PSI (1 bar) at 50F, city water will contain approximately 2.3% air by volume. If that same water is heated to 195 F – at the same pressure of 1 bar, it can only hold about 0.3% air by volume. Therefore a 145F temperature increase of 100 gallons of water will release 2 gallons of absorbed air.

It is also true that some of the air in water (both dissolved air and undissolved air microbubbles) can be *removed by lowering the pressure*. Gases (air) within water are very dependent on the pressure of the system. The concentration of a gas (such as air) in a fluid (such as water) is directly proportional to the partial pressure in the system – this is Henry's Law.

$$c = p_g / k_H$$

Where

c= solubility of dissolved gas
k_H= proportionality constant depending on the nature of the gas and the solvent (water in this example)
p_g= partial pressure of gas (Pa, psi)

For example, at 75 psi, similar to incoming city water pressure at 50F the water would have about 14% air by volume. IF the water drops only to just atmospheric pressure of 14.7 psi the % of air drops to 2.3% . So, for 100 gallons of water, 11.7 gallons of air can be removed – passively. The REALICE unit creates an intense sub-pressure lower the 1 bar o414.7 psi within its vortex.

This, however, should not be misunderstood that the VPT when applied as REALICE with typical city water pressures has its *primary impact* as the removal of dissolved gasses. The REALICE unit does impact dissolve air, but very little. The primary impact on the resurfacing water is the removing of undissolved free gasses in micro-bubble form. It is common in water piping systems that there is entrained air in the water (hot or cold) with some of it in the form of micro-bubbles which will impact resurfacing ice in rinks . The REALICE technology is an in-line hydraulic device that strips entrained micro-bubbles from the fluid flow.

HOW BIG IS A MICRO-BUBBLE?

There needs to be some perspective in understanding the range in size of micro-bubbles to better understand how difficult they are able to be seen in the water at an ice rink or resurfacing machine. One millimeter is about 1/25th of an inch. For reference the period at the end of a sentence is about 1/25th inch.

There are 1,000 micrometers (uM) to 1 millimeter. **Micro-bubbles** range from as large as 1/25th inch (1,000 micrometers) to 1 uM or 1/25,400th of an inch. Anything smaller is considered a nano-bubble.

Table 1 Inch, mm and uM comparisons and examples

mm	uM	inch
25.4	25,400	1
1 mm	1000 uM	0.0393
0.001	1 uM	0.0000393
1–10 µm – length of a typical bacterium		
~ 100 µm diameter human hair		

Summary

The vortex flow gives rise to strong pressure gradients, cavitation and shear forces. The radial pressure gradient in the vortex chamber causes a strong sub-pressure along the vortex axis. As mentioned, when using water, this sub-pressure forces micro air bubbles (un-dissolved air) to move inward toward the vortex axis where they coalesce into larger bubbles and are removed. The outlet of the REALICE unit fills the resurfacing machine. If there is enough un-dissolved air in the water, a “vacuum string” along the axis can be clearly visible through a transparent vortex generator and the now large macro bubbles exit the REALICE unit. If the pressure gradient is strong enough, cavitation occurs. The strong pressure gradient and removal of micro bubbles shifts chemical balances, giving rise to reactions that would not happen under normal flow conditions.

In the vortex generator, shear forces occur not only close to the wall, but also within the fluid itself. There are also shear forces close to the vacuum string along the vortex chamber axis. The powerful mixing capabilities of the vortex generator are largely due to the strong shear forces which cause a forced but still ordered convection in the flowing medium. The combination of pressure gradients and shear forces causes formation, aggregation or fragmentation of solid matter in the fluid under certain circumstances.

The Polymer Technology Group Eindhoven BV (PTG/e), an independent research institute, and part of the Eindhoven University of Technology[15] (TU/e) conducted an examination of the properties of VPT water. Samples were taken from municipal water in Holland before and after VPT treatment. Water treatment was made with a standard vortex generator at a water pressure of 3.5 bar (apx. 50 psi).

Primary Effects of VPT

Stripping Micro-bubbles

Micro air bubbles in water will be pulled into the low-pressure zone in the vortex chamber. The low pressure will cause them to expand and gather into large bubbles that can be easily extracted downstream the vortex generator. This process does not generally affect dissolved gases due to the typical low city water pressures found (45 – 85 psi). Substances that gather at bubble surfaces may follow the bubbles toward the vortex axis, aggregate and then be separated out.

[15] https://www.tue.nl/en/

Viscosity

A decrease in viscosity occurs after VPT treatment. The difference measured by Polymer Technology Group Eindhoven BV (PTG/e), was between 3 and 17 percent, depending on water quality and temperature. Gas micro bubble content affects the viscosity of water. As bubbles (un-dissolved air) are removed, a decrease in viscosity was measured.

Electrical conductivity

Based on the testing at the Polymer Technology Group Eindhoven BV there was an increase of 3% in electrical conductivity after VPT treatment in the PTG/e study.

Heat transfer

VPT treatment changed the melting behavior of ice. The heat capacity was 5% higher for ice and 3% higher for liquid water. Water with air has a lower density and a lower heat transfer ability.

Mixing

As the low pressure in the vortex chamber goes below the ambient pressure, gases or liquids can be sucked into the vortex chamber. The sucked-in fluid will be efficiently mixed with the spinning medium in the chamber. This process is very powerful in mixing for example water with air or other gases, or water with oil, thus producing stable emulsions.

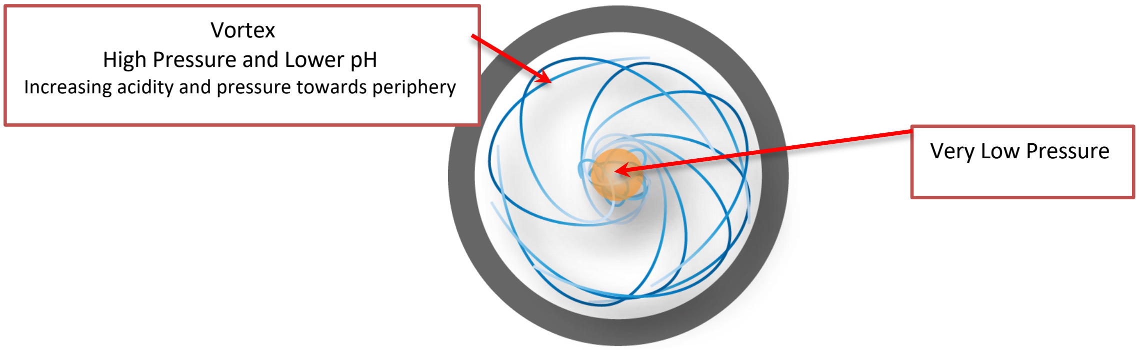
Cavitation and Pressure

With a low enough pressure along the vortex axis, cavities (microscopic bubbles) form in the medium. As they move into high pressure zones, they will rapidly implode, producing shock waves and a release of heat within a small volume. Vapor filled bubbles develop when the water pressure is below the prevailing vapor pressure.

- **Controlled Cavitation**: leads to the formation of lime particles in hard water. The process results in low pressure and high temperature micro-zone (solubility of CaCO3 decreases) causing the dissolved calcium and carbonate ions to react and form colloidal calcium carbonate crystals. This increases pH and allows the particles to act as incubation sites for dissolved calcium and carbonate ions to grow on, in lieu of, metal surfaces.
- **Fragmentatio**n: Already formed lime particles fragment as they move through the pressure gradients and shear forces
- **Precipitation**- nuclei formation: Calcium bicarbonate (CaHCO3)2 in the water is forced to precipitate out in the form of calcite (CaCO3) – primarily aragonite crystals which have minimal scaling properties – does not precipitate on warm surfaces. Such particles act as seeds (crystallization nuclei) for new lime growth. New lime formation will add to the lime particles rather than cause lime-scaling on the equipment.

The vortex flow from the system creates extreme pressure gradients and forces that limit or exclude the buildup of lime within the cooling tower supply. The strong hydrodynamic force in the vortex generator creates hydrodynamic cavitation changing the water chemical balance and affects the calcium crystals in the water.

The technology combines these effects to force the precipitation of calcium carbonate. As the pressure increases towards the periphery the solubility for CO_2 also increases. When CO_2 reacts with water as described in the following formula: $CO_2 + H_2O \rightleftharpoons H_2CO_3$ carbonic acid is the result. The pH level at a certain layer depends on the concentration of CO_2. When the pressure is increased towards the periphery there will be a difference in the pH level following the pressure gradient. In this case the pH level will *decrease* towards the periphery following the increased pressure.



The calcium ion precipitates and forms calcium carbonate $CaCO^3$ at a specific pH level. The pH level varies from the center to the periphery where the calcium ion will begin to precipitate during the reaction with H_2CO_3. The precipitation will occur in the moving water, within the VPT.

The calcium crystallization process in using VPT is due to the pressure gradient and the sheer forces inside the vortex. There is an interaction between water, the calcium ion and CO^2. CO^2 is more soluble in water as a function of pressure, i.e. higher pressure = higher solubility and makes the higher CO^2 concentration slightly acid together in the water. Since the pH level varies along the pressure gradient so that there is lower pH at the periphery and higher in the center of the vortex the calcium ion precipitates and forms calcium carbonate $CaCO^3$ at a specific pH level.

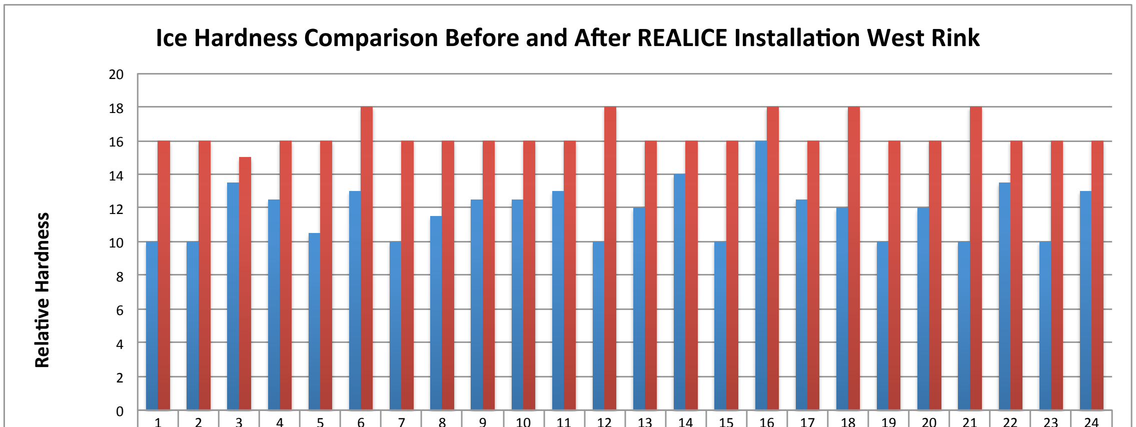
The water within the VPT does not form scaling on the walls of the VPT unit itself. The calcium carbonate in this way forms Aragonite and Calcite hard crystals due to the dynamic treatment in the vortex with its high sheer forces. Therefore, this precipitate is not available to coat warm surfaces such as heat transfer surfaces, reducing lime scale and can be both filtered with the PVT skid and/or blown-down as part of the typical tower maintenance.

The reduction in the scaling and fouling of the cooling tower increases the overall heat transfer of the cooling tower to near design conditions, thus improving overall plant efficiency. When enough lime particles have been formed under the extreme conditions of cavitation in the system, the chemical balance is shifted so that lime is dissolved rather than formed. This dissolving occurs on both new and old lime.

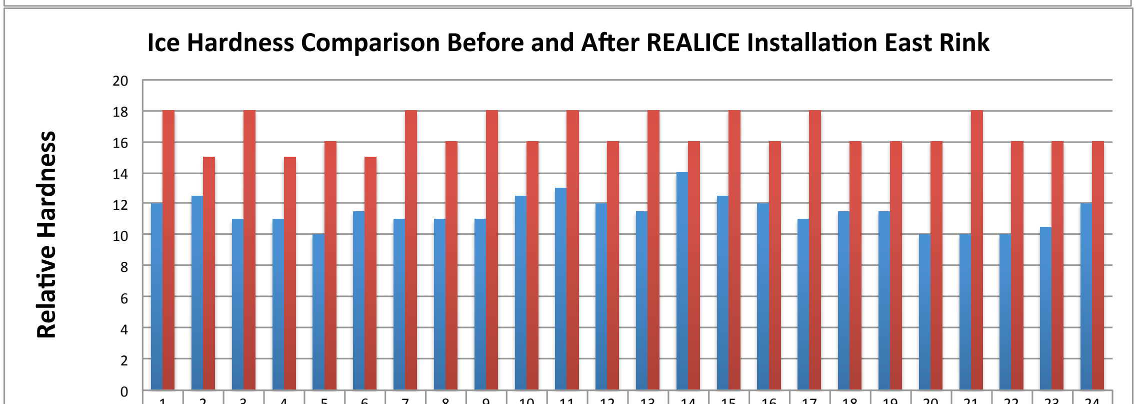
HARDER AND MORE UNIFORM ICE:

Southern California Edison (SCE) completed testing under a contract with Cypress Ltd. on the REALICE technology on two rinks in California to verify savings claims and that ice made using the technology would be of better quality after installation. The ice quality of the base case and the post install case (after installation) was measured by testing surface strength of contact using a Schmidt Hammer.

Figure 2 Ice Hardness Results for Each Test



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Pre REALICE	10	10	13.5	12.5	10.5	13	10	11.5	12.5	12.5	13	10	12	14	10	16	12.5	12	10	12	10	13.5	10	13
Post REALICE	16	16	15	16	16	18	16	16	16	16	16	18	16	16	16	18	16	18	16	16	18	16	16	16



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Pre REALICE	12	12.5	11	11	10	11.5	11	11	11	12.5	13	12	11.5	14	12.5	12	11	11.5	11.5	10	10	10	10.5	12
Post REALICE	18	15	18	15	16	15	18	16	18	16	18	16	18	16	18	16	18	16	16	16	18	16	16	16

- The conclusion is that the rebound or hardness numbers are as good or better after the installation of the REALICE system, which meets the intent of the measurement and verification process.
- For Rink A the ice was on average 39% harder post installation of REALICE with a high of 80% and low of 11 %.
- For Rink B the ice was on average 46% harder post installation of REALICE with a high of 80% and a low of 14%.
- The overall uniformity of ice strength is much better after the installation of the REALICE system. This means that the ice was more consistent in hardness across the entire rink after installation

IV. INSTALLATION

The installation of a REALICE System takes normally no more than 1-2 hours by certified plumber

100% of the water used for resurfacing must go through the REALICE unit – bypassing the unit will compromise savings and ice quality

ISO certified and tested for pressure, temperature and food safety