This article shall discuss the ice thermal storage systems using direct refrigerant. Brine circulated type ice thermal storage systems are discussed in a separate article.

Separate articles related to the ice thermal storage applications are:

1.0 Ice Thermal Storage in Air conditioning Application - Fundamentals. This article is for general views of ice thermal storage application.

2.0 Brine Circulated Ice Thermal Storage Systems. This article is for ice thermal storage systems using brine as the heat transfer fluid.

3.0 System Configuration for Ice Thermal Storage. This article is to deal with the system performance of an ice thermal storage system such as:

3.01 How the load should be determined.

3.02 How the refrigeration unit and the ice reserve unit should be arranged.

3.03 How the system performance of the system differs for ice priority mode and chiller priority mode.

3.04 How the refrigeration unit and the ice reserve unit should work together as a system.

3.05 The system operating conditions.

Direct refrigerant ice thermal storage is a system which is to supply the liquid refrigerant from the refrigeration unit directly to the ice builder instead of brine.
The advantages of using direct refrigerant system are:

1.0 Higher evaporative temperature and better power consumption.

2.0 Better system operating efficiency and system reliability.

3.0 Lower chilled water temperature and larger chilled water temperature range can be obtained to reduce size of the chilled water piping and to reduce the pumping horsepower of chilled water circuit.

4.0 Supercool air supply can be obtained for better indoor air quality and lower RH% in the conditioned space.

5.0 The air distribution ducting can be smaller, help to reduce the construction cost of air duct system and also reduce the energy usage of air distribution.

6.0 Reduces overall power consumption of the installation.

The disadvantages of the direct refrigerant ice thermal storage systems are:

1.0 The refrigeration system is somewhat special and is not a standard unit from most manufacturers.

2.0 The refrigeration system is more expensive.

3.0 Higher degree of system engineering skill and knowledge are required to design the system.

4.0 More field installation work to install the refrigeration system.

5.0 More refrigerant charge is required for the system.

6.0 More skilled operator is required to operate the system.

ICE BUILDERS:

There are various types of ice builders available from the market. The common use ice builder for use with direct refrigerant is as the following:
(A) **ICE-ON-COIL ICE BUILDER:**

Ice-on-coil is also called Static Ice. The ice builder is constructed by steel coil. The refrigerant is circulated through the steel coil; the ice is form outside of the coil.

Figure-1 shows the factory assembled ice reserve unit with tank. The Figure-2 shows the bare coil assembly for field erected system and the concrete tank with the coil inside of the concrete tank.

Unlike brine circulated ice builder, the ice melting of the ice on coil type ice builder is external. The Figure-3 shows that the relation of the refrigerant flow and water circuit. The ice making and discharge cycle functions of the ice builder are described as the following:

**Ice Making Cycle:**

The ice tank is full of water at the beginning of the ice making operation, the low temperature liquid refrigerant is circulated through the coil from the inlet "A" and leaving at "B". The liquid refrigerant is vaporized inside of the coil and the vapor is then returned to the suction of the compressor; the chilled water pump is not operating; a small air pump is bubbling the air for water agitation purpose inside the tank. The water contacted with the coil and it is frozen and become ice. The thickness of the ice on the coil at the end of ice making cycle depends upon the design of the ice builder and it is usually about 1" to 1-1/2".

**Air Conditioning Cycle:**

During the day time air conditioning cycle, the refrigerant flow is shut off, the water is pumped through the tank by the chilled water pump. The water is cooled down by contacting with the ice in the tank; the ice is melt and water is chilled from an inlet temperature of T2 to an outlet temperature of T1.

The coil is occupied with ice after the ice is made. Therefore, during the air conditioning cycle, the coil of the ice builder cannot be used for other function such as supplement cooling. In view of this, a separate heat exchanger is needed for supplement cooling for ice-on-coil type ice builder for air conditioning operation.

(B) **DYNAMIC ICE BUILDERS:**

Dynamic type ice builder is also called Harvesting type ice builder. The dynamic type ice system separates the functions of ice making and ice storage. The ice builder is not part of the storage. See Figure-4. The ice builder is usually located at the top of the storage tank. The ice drops down to the storage tank at each harvesting cycle during the ice making period.
Figure-1  Ice Builder Assembly
Static Ice (Ice-On-Coil)
Figure-2  Coil in Concrete Tank
Ice-On-Coil Ice Builder
Figure-3  Refrigerant & Water Flow  Static Ice Builder
Figure 4: Dynamic Ice Builder Plate Ice & Plate module
Basically, three types of Dynamic Ice makers are available from the market for ice thermal storage application:

I) Plate Ice.
II) Tubular Ice.
III) Flake Ice.

The basic theory for the three types of dynamic ice is the same except that the shape of the ice is different. The most common type of dynamic ice builder is the plate ice. Figure-4 shows a plate type dynamic ice builder system. The ice making section (ice builder) is located at the top of the ice/storage tank.

The dynamic ice builder has much ice harvesting cycles during the ice making operation. The ice is dropping down to the ice tank at each harvesting cycle.

The ice making and air conditioning operations of a dynamic ice system are explained as the following:

Ice Making Operation:

Ice Forming:

During the ice forming operation of the ice builder, the chilled water pump is not operating. The water in the tank is pumped by the ice water pump and circulated to the water distribution pan at the top of the ice builder (see Figure-5). The water flows down on the outside of the plates; the cold liquid refrigerant is circulated inside of the plates, the liquid refrigerant is vaporized and the water on the outside surface of the plate assembly is frozen (see Figure-5).

Ice Harvesting:

At the end of the ice forming cycle, the liquid line is closed and hot refrigerant gas is introduced into the inside of the plate instead of cold liquid refrigerant by a timer to defrost the ice and to break the bond between the ice and the plate. The ice drops down (see Figure-6) to the storage tank and harvesting cycle is completed.

The ice forming and harvesting cycle is repeated until end of the ice making operation or when the ice tank is full of ice.

It takes about 20 to 30 minutes to build the ice on the plate to a thickness of 1/4" and it requires about 20 to 30 seconds harvesting the ice.
Figure-5 Ice Making Dynamic Plate Ice

Figure-6 Ice Harvesting
The minimum defrost hot gas required for the defrosting for the plate type ice builder is about 170 psig for R-22. That means the condensing temperature of the refrigeration system for Dynamic Ice storage must be kept at not lower than 90.5°F any time no matter what outside temperature would be, otherwise, the system would not function properly.

**Air Conditioning Operation:**

The ice builder can be used as a chiller during day time operation. When the system is operated for air conditioning, the ice water recirculating pump is stopped; the chilled water pump is circulating the chilled water from the ice tank at a leaving temperature of T1. This chilled water from the tank is supplied to the heat exchanger to cool the system chilled water, say from 56°F to 34°F. The child water leaves the heat exchanger at the temperature T3. This child water is precooled by flowing over the plates of the ice maker where refrigerant is circulated to cool the water from T3 to a temperature of T2; the chilled water is further cooled down by contacting the ice in the tank to a leaving temperature of T1.

During the air conditioning supplemental operation, the compressor is running at a higher suction pressure, therefore, the liquid refrigerant supplied to the plates of the ice maker is at a higher evaporative temperature.

**(C) SLURRY ICE:**

The construction of a slurry ice maker is a shell within a shell. The low temperature refrigerant is circulated outside of the shell and the brine solution is circulated inside of the shell.

Figure-7 shows the slurry ice system. The brine solution flows through the ice maker shell. The ice and ice crystal are formed inside of the shell and a blade type rotating vane which is driven by a motor externally to scrub the ice and the ice is in a small slurry type particles which are carried away by the brine solution, the solution and the slurry ice is pumped to a remote storage tank where the slurry ice is float on top of the tank. The pure solution is recirculated back to the shell to make ice.

During the air conditioning operation (see B - Discharge Mode), the return brine solution is assumed at 50°F from the air handling unit. The brine solution is cooled down to 40°F by the ice maker shell and through the ice storage tank, the brine solution is further cooled down to 34°F leaving temperature.
Figure-7 Slurry Ice System
The evaporative temperature required for slurry ice builder is usually lower than the requirements of ice-on-coil and dynamic ice builders.

ICE BUILDER MANUFACTURERS:

The major manufacturers who provide the ice builder for direct refrigerant type ice thermal storage application are as the following:

Ice-on-coil  - BAC
             - Chester-Jensen
             - Evapco
             - Perma Pipe

Dynamic Ice (Plate ice)  - Morris and Associates
                         - Mueller
                         - Turbo

Slurry Ice  - Sunwell

REFRIGERANT FEED FOR THE EVaporATOR:

The refrigerant feed to the ice builder is usually arranged for liquid recirculation (overfeed) or flooded. Direct expansion is not recommended and it is suggested not to use for any ice thermal storage installation. The refrigerant used in direct refrigerant ice thermal storage system can be either R-22 or R-134a or even R-717 (Ammonia).

Refrigerant feed is the method how the refrigeration is fed through the evaporator (ice builder). It is generally classified into three categories as the following:

(A) Direct Expansion.
(B) Flooded.
(C) Liquid Recirculation.
**DIRECT EXPANSION:**

Direct expansion is also called dry expansion. Figure-8 shows the typical arrangement of a direct expansion circuit. The typical phenomenon of a direct expansion refrigerant circuit is that the refrigerant leaving the evaporator coil is superheated and it is not saturated.

The advantages of using direct expansion are:

I. Low Cost.
II. Simple.

The disadvantages of using direct expansion are:

I. For short refrigerant circuit only.
II. Limited size of DX (Direct Expansion) valve.
III. Superheated gas inside the evaporator.
IV. Un-even temperature distribution.

**FLOODED EVAPORATOR:**

In a flooded refrigerant circuit, the refrigerant flow through the evaporator is by natural force. The Figure-9 shows the flooded evaporator. The liquid from high pressure receiver flows through a liquid level control valve to the surge drum which is located above the evaporator. The evaporator is entirely flooded with the liquid refrigerant. The liquid refrigerant inside of the evaporator is vaporized, gas and liquid flow to the surge drum where the gas is separated and returned to the compressor suction.

The basic requirement of a flooded system is that the suction gas from a flooded evaporator is saturated.

Flooded arranged is acceptable for small capacity ice thermal storage systems and it not recommended for large installation.

The advantages of a flooded arrangement:

I. Even evaporative temperature in the evaporator.
II. For small size ice builder.
III. Better heat transfer efficiency than DX.
Figure-8  Direct Expansion Heat Exchanger

Figure-9  Flooded Type Arrangement
The disadvantages of flooded evaporator:

I. More complicated to design.
II. More complicated to install.
III. More expensive.

LIQUID RECIRCULATION:

Liquid Recirculation is also called Pump Circulation or Liquid Overfeed. Liquid recirculation system is to pump the liquid refrigerant through the evaporator (the ice builder). Figure-10 shows the liquid from high pressure receiver flows to the pump circulation receiver through a liquid level control valve which is also an expansion device. The liquid temperature inside the pump circulation receiver is the same as the evaporative temperature of the ice builder. The liquid is pumped through the ice builder by the liquid pump, portion of the liquid is vaporized; the liquid and gas mixture is turned to the pump receiver where he gas/liquid is separated. The saturated refrigerant gas is returned to the compressor suction.

The flow rate through the evaporator is usually increased to few times more than the normal refrigerant flow needed for the load to ensure good heat transfer. In a R-22 liquid recirculation system, the pump ratio is 3:1. That means the pump is circulating three times more refrigerant than the normal rate. In this case, only 1/3 of the liquid is vaporized. 2/3 of liquid with 1/3 of gas is returned to the pump receiver.

Liquid recirculation is recommended for all the direct refrigerant ice thermal storage installations. The advantages and disadvantages of using liquid recirculation refrigeration system are as the following:

The advantages of liquid recirculation system:

I. Best heat transfer efficiency.
II. Most even temperature in the evaporator.
III. No limit in size and capacity.

The disadvantage of liquid recirculation system:

I. More complicated to design.
II. More difficult to instal.
III. More expensive for the equipment.
IV. Higher installation cost.
Figure-10  Liquid Recirculation Arrangement
REFRIGERATION SYSTEMS and ICE BUILDERS:

The refrigeration system for ice thermal storage can be either field erected or it can be factory packaged. The compressor used is usually an industrial type screw compressor in most cases.

LIQUID RECIRCULATION SYSTEMS:

Figure-11 shows a typical liquid recirculation refrigeration system which consists of the following major components:

(a) Screw compressor unit.
(b) Water cooled condenser.
(c) High pressure receiver.
(d) Liquid recirculation package.
(e) The evaporator.

For ice thermal storage application, the evaporator is the ice builder.

Water cooled condenser is shown in the Figure-11, however, it can be replaced by other type of condenser such as evaporative condenser, or air cooled condenser to suit the application.

Figure-12 shows a liquid recirculation system with an evaporative condenser. The evaporative condenser is usually located at outside of the building.

Single refrigerant pump is shown in both Figures 11 and 12. Usually, a dual pumps with one stand-by pump is arranged for the liquid recirculation package for continuous operation. The dual refrigerant pump arrangement is shown in Figure-10.

Figure-13 shows a diagram for a liquid recirculation partial storage ice thermal storage system with static ice builder and a supplement chiller. the functions of the system are described as the following:

1.0 The refrigerant gas is compressed by the screw compressor, vapor is condensed in the evaporative condenser and the liquid refrigerant flows to the high pressure system receiver.

2.0 Night time ice making operation:

During the ice making cycle, the ice water pump is not operated, the refrigerant valves V2 are opened and the valves V1 are closed. The compressor is operated at a lower suction pressure for the ice making duty. The liquid in the liquid recirculation receiver is pumped through the coil of the ice builder to make ice. Ice is stored in the ice reserve unit for day time air conditioning use.
Figure-11 Liquid Recirculation System
Water Cooled Condenser
Figure-12 Liquid Recirculation System with Evaporative Condenser
Figure-13 Ice Thermal Storage
Ice-On-Coil Ice Builder Refrigeration System
3.0 Day time operation:

The refrigerant valves V2 are closed and valves V1 are opened. The refrigerant pump is not operating.

The compressor is operated at a higher suction pressure for the supplement air conditioning duty.

The refrigerant liquid is supplied to the supplement chiller. The system return chilled water at 56°F is cooled down to an intermediate temperature of 47.72°F by the supplement chiller; the chilled water is further cooled down to a leaving temperature of 36°F through the plate type heat exchanger by circulating 33°F ice water which is supplied by the ice water pump from the ice reserve unit. The 36°F primary leaving chilled water is supplied to the air side system for air conditioning.

Figure-14 shows the refrigeration system with a dynamic ice builder. The primary chilled water is cooled by the ice water from T2 to T1 through a plate type heat exchanger.

Figure-15 shows a liquid recirculation refrigeration system with supplemental chiller, an oil still/recovery system and a heat recovery condenser for hot water supply. The cooling water for screw oil cooling is supplied from a separate cooling coil in the evaporative condenser.

Figure-16 shows the refrigeration system with ice on coil type ice builders. The return primary child water is returned from the air side at 56°F, the water is cooled down to 45.82°F by the supplemental chiller and is further cooled down to 36°F leaving by the ice.

Figure-17 shows the refrigeration system with dynamic ice builders.

FLOODED SYSTEMS:

The Figure-18 shows a static ice maker with flooded refrigerant surge drum. The refrigeration system is with evaporative condenser and a supplement chiller. The functions of this ice thermal storage system are as the following:

During ice making cycle, the refrigerant valves V2 are opened and valves V1 are closed, the liquid refrigerant is supplied to the ice builder, the liquid is vaporized in the coil of the ice builder, the saturated refrigerant vapor is returned to the compressor suction.

When the system is operated in air conditioning mode, the refrigerant valves V1 are opened and valves V2 are closed. The compressor is running at a higher suction pressure. The refrigerant liquid is supplied to the supplement chiller to pre-cool the chilled water at an entering temperature of 56°F (T2). The liquid is vaporized in the supplement chiller and the saturated gas is returned to the
Figure-14 Ice Thermal Storage Dynamic Ice Builder Refrigeration System

T1 Chilled Water Supply to Air Side

T2 Chilled Water Return from Air Side
Figure-17  Ice Thermal Storage System
Liquid Recirculation
Dynamic Ice
Figure-18  Ice Thermal Storage System
Floored Dynamic Ice Maker
compressor suction. The return chilled water is pre-cooled to an intermediate temperature of Ti. The ice water is pumped through the ice builder and circulated through the plate type heat exchanger to cool the chilled water from the intermediate temperature Ti to 36°F leaving.

Figure-19 shows the same system as the system shown in Figure-18 except the following:

1.0 Automatic oil return still and oil return system is added for the ice builder and the supplement chiller.

2.0 The water for oil cooling for the screw compressor is supplied from the evaporative condenser.

The direct refrigerant refrigeration system for ice thermal storage is usually field erected system. However, the refrigeration system can be partially factory skid mounted to minimize the field erection work. The factory skid mount arrangement can include the compressor unit, water cooled condenser, receiver and controls. But, the evaporative condenser or air cooled condenser, if used instead of water cooled condenser is usually shipped separately for field installation. Liquid Recirculation Unit is usually a factory packaged unit with liquid level control valve and control panel.

OIL STILL AND OIL RETURN SYSTEM:

For direct refrigerant systems, automatic oil return system is always recommended and it is to be incorporated with the refrigeration system to return the lubrication oil from the evaporator automatically back to the compressor.

SUPPLEMENT CHILLER:

In a partial storage ice thermal storage system, the refrigeration system is to supply the refrigerant to the ice reserve unit (ice builder) to make the ice during off-peak hours in the evening and the same refrigeration system is also to be operated to supply refrigerant to provide supplement cooling for air conditioning as needed during air conditioning cycle. A supplement chiller is required if ice on coil type (Static Ice) ice builder is used, because the coils of the ice-on-coil type ice builder is full of ice and it cannot be used for the supplement air conditioning duty at discharge cycle. On the other hand, a dynamic ice builder may be used for supplemental water chilling duty, because the ice is harvested to the ice tank instead of attached to the plates.
Figure-19  Ice Thermal Storage System
Flooded Dynamic Ice Maker
With Oil Still
PERFORMANCE OF ICE-ON-COIL ICE BUILDER:

The Figure-20 shows a typical performance of an ice-on-coil ice builder. The curve "A" or "B" are the evaporative temperature inside the coil of the ice builder. The curve represents the temperature changes during the ice making period.

Curve "A" represents a coil "A" which is having less square feet heat transfer area and thicker ice thickness; Curve "B" represents an ice builder which is having larger heat transfer surface area and thinner ice thickness. The evaporative temperature of coil "B" is generally higher than the coil "A".

At the beginning of the ice making cycle, the coil is bare without ice and the ice thickness is zero. The compressor is running at a higher suction temperature. The suction pressure of the compressor decreases when the ice is being built on the coil. The heat transfer resistance increases when the ice thickness increases and therefore, the compressor is required to run at lower suction pressure. For the coil "A", the beginning ET is about 25.5°F, but, the final pulling down ET at the end of ice making cycle is about 13.4°F.

The Figure-20 shows that the capacity and the evaporative temperature change all the time during the ice making cycle. The compression head changes would even greater when the compressor is switched to air conditioning supplement operation from the ice making operation. Therefore, the compressor used must be variable head machine such as screw compressor instead of constant head machine such as centrifugal.

A screw compressor with automatic variable internal volume ratio control can adjust the internal volume ratio (Vi) of the screw compressor to provide maximum efficiency at any head requirement and it is the best suit for the application. A compressor with variable internal volume ratio (Vi) could save annual power consumption up to 35% in addition to the operating efficiency of ice thermal storage application.

Screw compressor can be with economizer also to improve the power consumption of the compressor. This feature might not be available for a standard brine chiller, but, it is very easy to be accommodated in a direct refrigerant system, because, the refrigeration system is usually specially designed.

The best energy efficient refrigeration system of a direct refrigerant ice thermal storage system shall be the combination of the following features and arrangements:

1. Screw compressor with variable Vi control.
2. Economizer.
3. Evaporative condenser.
Figure 20 Typical Performance
Ice-On-Coil Ice Builder

TR, ET and percent ice build vs time
ICE ON PIPES

PERCENT ICE BUILD
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

TR
1300
1250
1200
1150
1100
1050
1000
950
900

ET
28°
26°
24°
22°
20°
18°
16°
14°
12°
10°

TIME, HOURS
0 1 2 3 4 5 6 7 8 9 10 11 12
The oil cooling of the screw compressor can be either by liquid injection, or water cooled or thermosyphon oil cooler. Water cooled is recommended in ice thermal storage when the system is using water cooled or evaporative condenser.

REFRIGERANT PIPING:

The refrigerant piping design of a direct refrigeration system is very important. The piping sizes and fitting selected are to be reasonable. The pressure drops in the piping system are to be reflected and included in the compressor selection and heat exchanger design.

The following curves and data for R-22 will provide the necessary information to design the refrigerant circuits of a refrigeration system:

Figure-21: Suction Line Capacities.

This table provides quick reference of refrigeration capacities and pressure drops of the different suction pipe sizes at various saturated suction temperature.

Figure-22: Discharge Line Capacities.

This table provides quick reference of refrigeration capacities and pressure drops of the different discharge pipe sizes based on 105°F condensing temperature and 40°F saturated suction.

Figure-23: K-factors for valves and fittings.

Figure-24: Equivalent Lengths of Valves and Fitting.

Figure-25: Flow Rate Per Tons of Refrigeration.

This curve provides refrigerant flow rate of R-22 per TR. The curve is based on total vaporization.

Figure-26: Vapor Pressure Drop in Steel Pipe.

Refrigerant vapor pressure drop through steel pipes.

Figure-27: Vapor Velocity in Steel Pipe.

Refrigerant vapor velocity in steel pipes.
<table>
<thead>
<tr>
<th>LINE SIZE (inches)</th>
<th>Saturated Suction Temperature (°F)</th>
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<tr>
<td></td>
<td>-40</td>
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<tr>
<td></td>
<td>1/4</td>
</tr>
<tr>
<td>1 IPS</td>
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</tr>
<tr>
<td>1/4</td>
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<td>0.43</td>
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**NOTES:**

1. Based on fluid flow at 10°F saturated condensing temperature.
2. "IPS" data based on Schedule 40 steel piping. "OD" data based on Type L copper tubing.

**Figure-21** Suction Line Capacities - Tons
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<th>OD</th>
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NOTES: * Based on fluid flow at 105°F saturated condensing temperature and 40°F saturated evaporating temperature
  **IPS** data based on Schedule 40 steel piping except that liquid lines 1½" and smaller are Schedule 80
  "OD" data based on Type L copper tubing

**Figure-22** Discharge and Liquid Line Capacities - Tons
### FERROUS VALVES AND FITTINGS

<table>
<thead>
<tr>
<th>LINE SIZE (INCHES)</th>
<th>GLOBE VALVE</th>
<th>ANGLE VALVE</th>
<th>SHORT-RADIUS ELL</th>
<th>LONG-RADIUS ELL</th>
<th>TEE, LINE-FLOW</th>
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### NON-FERROUS VALVES AND FITTINGS

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**NOTES:**

1. $K = 2gh/V^2$
2. Based on Schedule 40 pipe
3. Based on Type L copper tubing
4. For screwed valves and fittings, use ferrous K-Factors
5. For OD sizes above 2¼", use welded ferrous K-Factors

---

**Figure-23** "k" Factors - Valves & Fittings
## FERROUS VALVES AND FITTINGS

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## NON-FERROUS VALVES AND FITTINGS

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NOTES: ¹ Lₐ = K(D/ν)

¹ Friction factors () determined at "practical" Reynolds Numbers based on 40°F suction lines having pressure-drop of 1.8 psi/100 ft
² Based on Schedule 40 pipe
³ Flare, sweat, flanged, etc., and based on Type L copper tubing

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Figure-24 Equivalent Lengths - Valves & Fittings
Figure-25  Flow Rate Per Ton Of Refrigeration
The refrigerant piping for the refrigeration system should be properly designed and the performance of the compressor/condenser should be balanced with all the penalties and piping pressure drops.

The compressor capacity decreases when the suction pressure drop increases and the power consumption increases accordingly. Higher pressure drop in suction line will greatly affect on the cost and performance of the system. Therefore, the suction pressure drop in the suction line should be carefully selected. For ice thermal storage application, the suction line piping pressure drop should be within 1 to 2.5 psi per 100 feet of piping.

Discharge pressure drop should be also added to the penalty of the compressor selection. The discharge line pressure drop should be within 2 to 4 psi per 100 feet; the liquid lines are normally sized for a low pressure drop to avoid flash gas.

When the liquid flows vertically in a riser or when pressure drop may cause flashing, liquid subcooling should be used to eliminate the flash gas.

The design of liquid recirculation circuit is not the same as regular refrigeration system. A regular refrigerant circuit only involves with single phase flow of either liquid or vapor. However, liquid recirculation system involves with two phase flow in the suction line between the ice builder and the liquid recirculation receiver, the refrigerant flow rate for the evaporator is also not the same as compared to flooded or DX.

The refrigerant circulation rate for liquid recirculation system should be designed for a ratio of more than one. This means the amount of liquid being pumped through the ice builder is more than the liquid vaporized. The experience circulation rates for R-22 is 3:1, the liquid refrigerant fed through the ice builder is three times more than the refrigerant needed to boil off in the ice maker, the refrigerant in the return line from the ice builder to the liquid recirculation receiver consists of one part of vapor and two parts of liquid. The circulation rate for R-22 is normally 3:1, however it should always be verified by the ice maker manufacturer.
Figure-28  R-22 Liquid Velocity and Pressure In Steel Pipe
Figure-29  R-22 Liquid
Relation Of Pressure Change to Elevation Difference
Figure 30  R-22 Pressure Drop In Valves and Fittings

NOTE: PRESSURE DROP DOES NOT ALLOW FOR FLAShING FLOW OR LIQUID FLASHING.
The pressure drop between the ice builder and the liquid recirculation receiver should be designed for two phase flow instead of single phase. The pressure drop for R-22 at 3:1 circulation rate is about 6 times more than the single phase vapor pressure drop in an ice thermal storage system application.

DESIGN EVAPORATIVE TEMPERATURE:

The evaporative temperature of a direct refrigerant ice thermal storage system depending upon the type of ice make is used. The operating evaporative temperature of an ice on coil type ice maker changes all the times. The design evaporative temperature for an ice on coil ice maker is an average ET and it should be given by the ice maker manufacturer for a given selection of the ice maker. The condensing temperature for static ice system can be as low as 60°F. Therefore, the refrigeration system design should take the advantage of this feature to save energy.

The operating evaporative temperature for dynamic ice is almost constant and the condensing temperature is also almost constant. The design ET and minimum CT are also should be given by the ice make manufacturer.

The design evaporative temperature for slurry ice type ice maker is also constant. However, the condensing temperature can be lower because no defrost function is involved with slurry ice system.

CHARGE AND DISCHARGE EFFICIENCY:

All the ice builders have charge and discharge efficiency. Charge efficiency is how easy to store the ice during ice making cycle at the design evaporative temperatures, i.e. the TR-HR to be put into the ice reserve unit. The discharge efficiency is the TR-HR to be taken out from the ice reserve unit at the desired design chilled water temperature.

Unlike brine circulated ice builder, the direct refrigerant ice makers have very good charge and discharge efficiency even at the final hour of discharge, because the ice melting for direct refrigerant is always arranged for external melting. Internal ice melting cannot be arranged for direct refrigerant ice builders.

The ice builder must meet both the charge and discharge capacities and also the ice maker unit selected must be able to be installed in the space provided. The refrigerant piping should be design to provide even distribution of the liquid refrigerant. The hydraulic flow of the ice water through the ice makers in contact with the ice should also be designed for even flow to avoid melting problems.
The ice builder having melting problem in direct refrigerant ice thermal storage system is the problem that the chilled water hydraulic flow arrangement cannot make even contact with the ice. Therefore, it is more important to check the hydro/thermal short circuit problem than to check the discharge efficiency in a direct refrigerant ice thermal storage system.

SYSTEM CONFIGURATION:

The system configuration of an ice thermal storage system using direct refrigerant ice builders should also follow the same system design criteria as outlined in the article of ITS – System Configuration.