GEF - UNIDO - BEE PROJECT

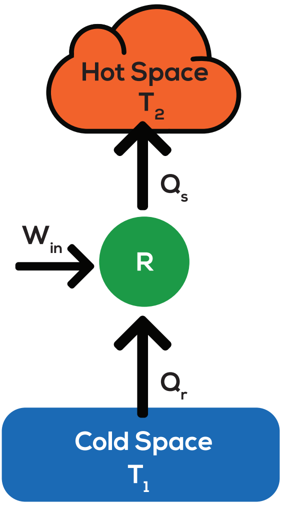
on

“Promoting EE/RE in selected MSME Clusters in India”

INDUSTRIAL REFRIGERATION

Refrigeration – Basic Principle

Transfer heat from cold space to hot space with work input



Measured in Tons of Refrigeration (TR)

One TR -Amount of heat to be removed to freeze one ton of liquid water at 0°C into ice at 0oC in 24 hrs

Equivalent to 3024 kCal/hr

$$\text{COP} = \frac{\text{Amount of heat to be taken out}}{\text{Amount of work required}}$$

$$\text{COP} = T1 / (T2 - T1)$$

Where,

T1 = Evaporator temperature, in K
T2 = Condenser temperature, in K

Therefore,

COP = Maintain at higher T1 or Maintain at lower T2

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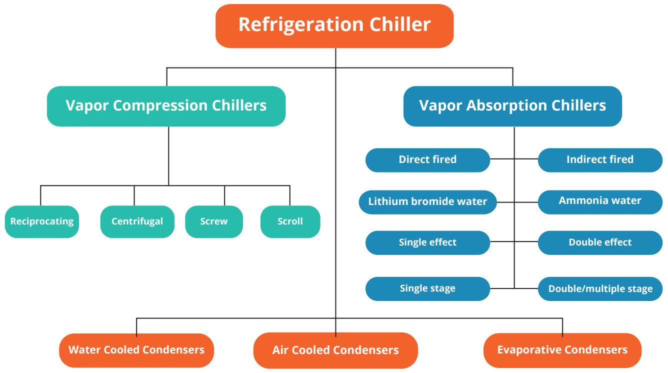
Classification of Chillers



Performance Terms

Tons of refrigeration (TR)

- 3024 kCal/h, 12,000 Btu/h or 3.516 thermal kW

$$\text{Net Reffrigeration Capacity(TR)} = \frac{m \times C_p \times (t_{in} - t_{out})}{3024}$$

Where,

m = Mass flow rate of chilled water, kh/hr
Cp = Specific Heat, kCal/kg°C
tin = Chilled water tempreture at evaporator inlet °C
tout = Chilled water tempreture at evaporator Outlet°C

kW/ton rating is ratio of Measured compressor power (kW) to Net refrigeration Capacity (TR)

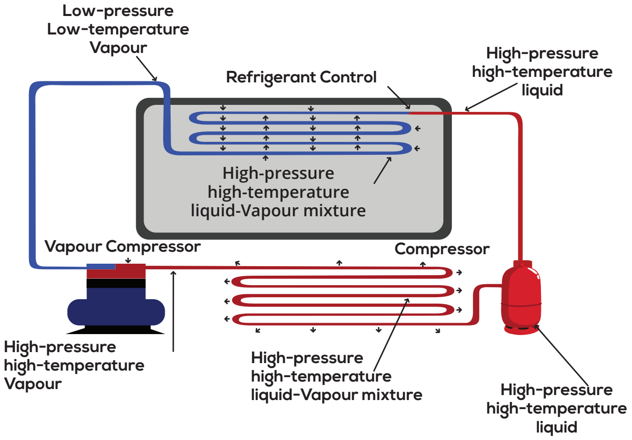
$$\text{kW/ton rating} = \frac{\text{Measured compressor power, kW}}{\text{Net refrigeration Capacity(TR)}}$$

$$\text{Coeficient of performance (COP)} = \frac{3.516}{\text{kW/Ton rating}}$$

$$\text{Energy Efficiency Ratio(EER)} = \frac{12}{\text{kW/Ton rating}}$$

COP = 0.293 EER	EER = 3.413 COP
kW/Ton = 12 / EER	EER = 12 / (kW/Ton)
kW/Ton = 3.516 / COP	COP = 3.516 / (kW/Ton)

Basic Cycle
Vapor Compression Cycle



Compressor
Heart of Refrigeration System

Compresses vapor refrigerant from evaporator to condenser pressure. Compressor are selected based on the application & capacities.

Types of Compressor in Industrial Refrigeration

1. Reciprocating Compressor

They are selected if the refrigeration capacity is less than 350 kW (100 TR). They are suitable

- Small capacity
- Relatively cheap

2. Screw Compressor

- Automatic Capacity Control from 10% to 100%
- Can operate with low suction pressure and have higher COP

3. Centrifugal Type

High Discharge pressure

- Scaling
- Air Ingress
- Results in high power consumption
  Sometimes High Pressure trip

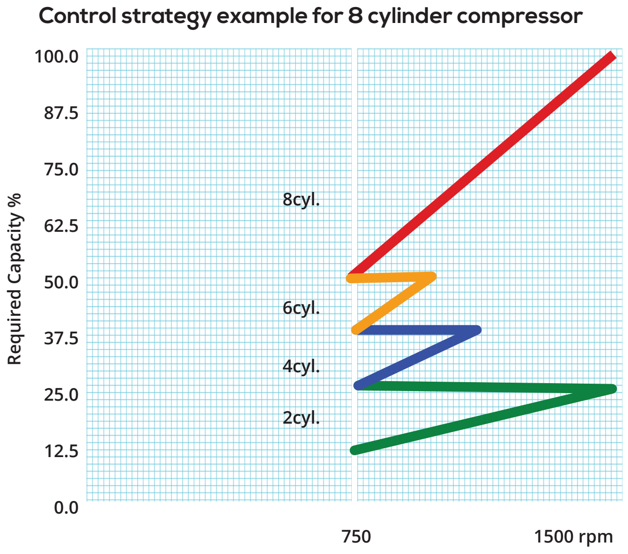
Low Suction pressure

- Low capacity utilization
- Higher power consumption
- Overdesign/Excess charge of refrigerant

Comparison of Centrifugal, Reciprocating & Screw Compressors

Description	Resiprocating	Centrifugal	Screw
kW/TR at 10°C chilled water tempreture	0.8 - 0.9	0.38 - 0.70	0.55 - 0.75
Capacity Range	>0.5 TR	90 TR	> 50 TR
Cost Compassion w.r.t. Resiprocating	--	50% Higher	30% Higher

VFD Capacity Control Reciprocating Compressor



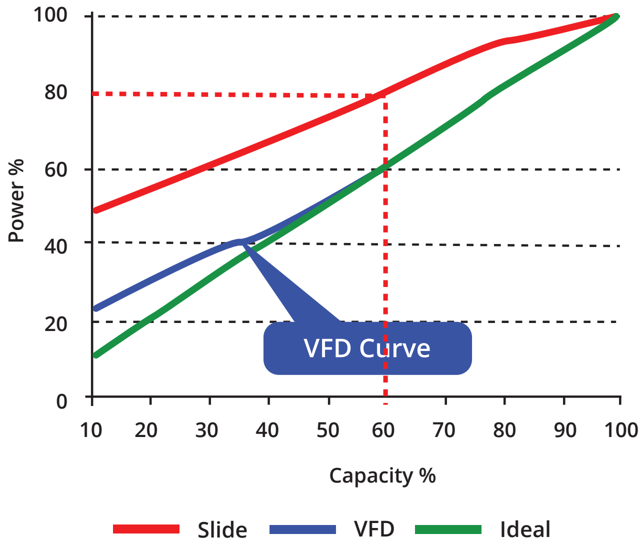
Reciprocating Compressor

VFD Capacity control

VFD Compressor capacity control - Resiprocating

- Pistons and VFD actuate together for compressor capacity
- VFD speed is determined by suction pressure PID control
- There is no dead band (Ramp up/down time is max 30s)
- More linear control possible (unite steps + linear control)
- Minimum speed must be maintained (Motor refrigeration, Oil pressure)

VFD Capacity Control Screw Compressor



Reciprocating Compressor

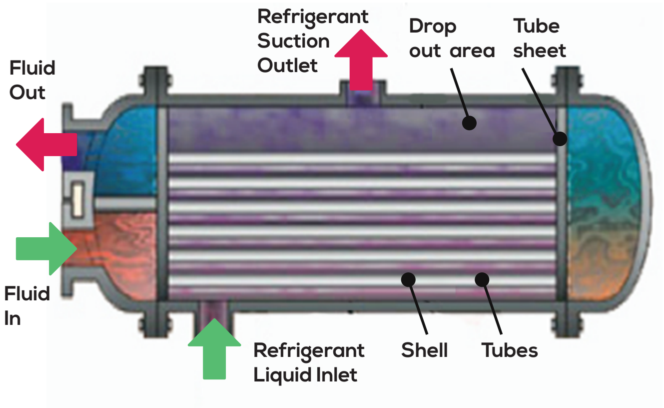
VFD Capacity control

**VFD Compressor capacity control
- Screw**

- Slide Valve and VFD actuate together for compressor capacity
- VFD speed is determined by suction pressure PID control
- There is no dead band (Ramp up/down time is max 30s)
- Faster system response allows higher tempreture operation
- Compressor COP is linear uptp 60% of the capacity
- Minimum speed must be maintained
  (Motor refrigeration, Oil pressure)

No losses upto 60% of nominal Speed

Condensers



Condenser reject heat to atmosphere

- **Process heat**
- **Energy input to Compressor**

Heat rejection ratio depends on

- Loading on condenser per unit of refrigeration
- Depends on COP, inturn on Condenser & Evaporator temperatures

Condensation pressure

- Depends on temperature of available cooling medium

Air infiltration in condense

- Air remains as non condensable gas
- Decreased heat transfer & increased condenser pressure
- Reduced evaporator efficiency
- Increase in specific power consumption

Effect of cooling water system on refrigeration compressor

Cooling water temperature

- Cooling water temperature should be as low as possible
- For every 1°C drop in approach, the reduction in compressor power : 4 to 5%

Typical design ΔT of cooling water (CW) across condenser : 4 to 10 ° C

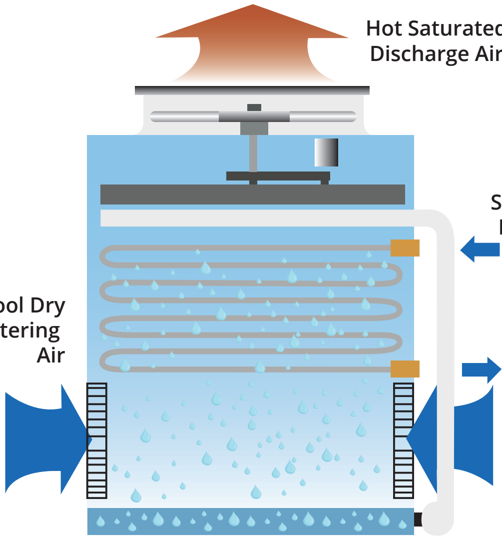
CW in → (30°C) **Refrigeration condenser** (34°C) → **CW out**

ΔT = 4°C

High ΔT

- Means less cooling water flow (reduction in pump power)
- Slight increase in compressor power
  - Can be off-set by increase in condenser area

Evaporative Condenser



Features

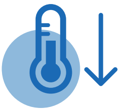
- Improved water to air contact within coil
- Higher water flow rate over coil
- Enhanced heat transfer η
- Lower condensing temperatures
- Reduced system power

For 150 TR plant need 18.5 KW for PHE Cond. With C.T combination as against 9.7 KW for Evaporative Condensers

Effect of Evaporator Temperature

Effect of evaporator temperature for same condenser temperature

Decrease in evaporator temperature from 5°C to -20 °C → **Increase in power consumption by 89% (theoretical)**



Effect of Evaporator Temperature

Effect of evaporator temperature for same condenser temperature

Decrease in evaporator temperature from 5°C to -20 °C → **Increase in power consumption by 89% (theoretical)**

Effect On COP with increase in Evaporator Temperature

Condenser temperature 30°C Evaporator temperature -5°C	→	Condenser temperature 30°C Evaporator temperature 0°C
$COP = \frac{(273 - 5)}{(273+30) - (273 - 5)} = 7.65$		$COP = \frac{(273 + 0)}{(273+30) - (273+0)} = 9.1$

If we increase evaporator temperature, COP will Increase

Main Refrigeration Load in dairies

Chilled Water Load

1. Milk Chiller

- **Raw Milk**
  Milk is chilled using chilled water from 34 °C to 4 °C
- **Tanker Milk**
  Chilled milk is collected from various chilling center is chilled from 10°C to 4°C

2. Milk Pasterization

- Milk Chilled in Milk Chiller in further pasteurized and then cooled by Chilled Water from 14 °C to 4 °C

3. Buttermilk Chiller

- 45°C to 4°C

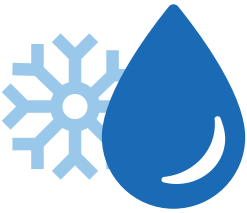
4. Ageing Tanks

- 8°C to 4°C

Direct Referigeration Load

1. Milk Cold Rooms
2. Butter Cold rooms
3. Dahi Cold Room
4. Blast Breezers

Types of Chilled Water Generation



IBT SYSTEM

This is conventional system

ICE SILO

Vertical cylindrical vessel with SS spiral coil inside acting as evaporator and accumulates upto 40mm to 50mm ice

IBT/ ICE SILO + PRE CHILLER SYSTEM

A combination of IBT And Pre Chiller depending upon load histogram.

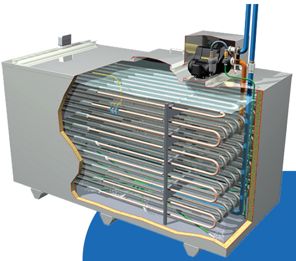
PHE CHILLER

- Chilled Water PHE
- Chilled Glycol System for Deep Chilling

IBT SYSTEM

The IBT tanks are basically a thermal storage system, storing the energy in the form of chilled water/Ice bank. To meet the demand supply gap the IBT tanks are provided as buffer to meet the process chilled water demand

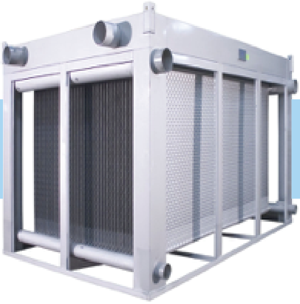
- Thermal Storage of energy available
- Refrigeration plant capacity smaller
- Latent heat available
- Safe during power cuts/ break downs

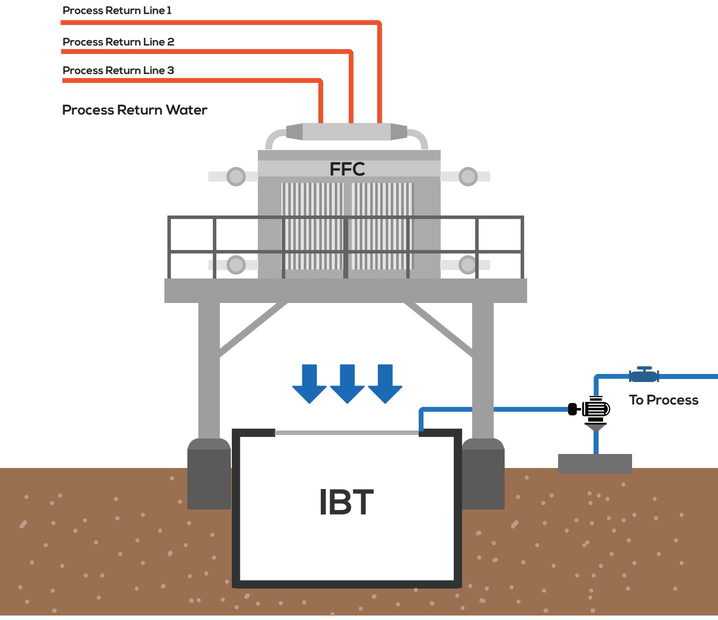


Total Load = 5, 292 TR / day
Average Load / 20 Hrs = 264.6 TR
Selection of coil length normally thumb rule 110 -120 ft /trv

Falling Film Chiller/Pre Chiller

It is used to prechill the return water from process and fed into IBT for further chilling. The above system is ideal if the process return water is at temperature more than 10°C

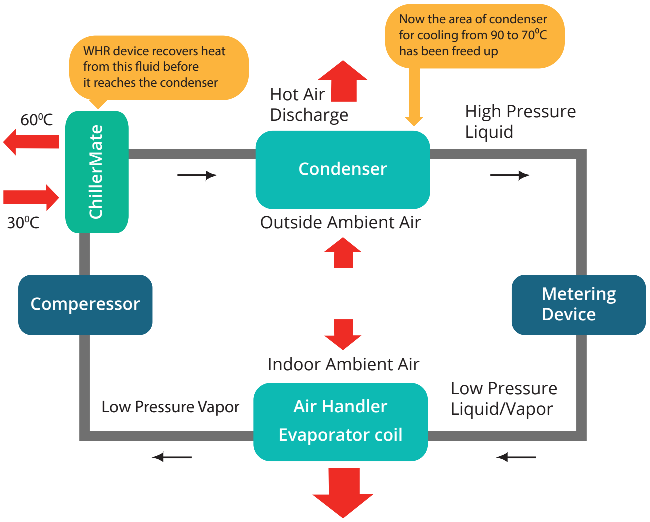




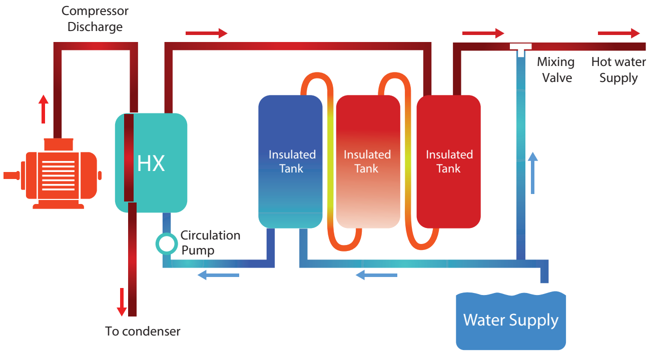
	IBT System	IBT cum Pre chiller
Total handling of milk	2.00 Lakhs	2.00 Lakhs
No of compressor	2 nos screw (1w+1S)	2 nos screw (1w+1S)
Comp. connected motor working	1nos. x 215 HP	1 no. x 180 HP
Suction/ Cond temp.	-10°C / 38°C	-5°C / 38°C
System Details	IBT	Pre chiller with IBT
Liq. pump system	YES	YES
Condenser Type	Evaporative Condenser	Evaporative Condenser
Refrigeration Capacity	150 TR	150 TR
Comp. BKW/ TR	0.95	0.782

Waste Heat Recovery from Chiller Compressor

The temperature of the discharge gas from compressors is generally 80⁰C and contain a good amount of heat within which goes to condenser for rejection. Every dairy require hot water at 60~65 ⁰C for cleaning and washing of various equipment in Dairy. This free heat of discharge gas can be utilized by installing a De-superheater to generate hot water.



Schematic for heat recovery Milk Chilling Center



Comparison of refrigerant characteristics

Refrigerant	ODP	GWP 100 years	Safety Group	COP ratio	Refrigeration Capacity	Discharge Pressure MPa	Discharge Temp.⁰C
HCFC-R22	.055	1700	A1	1	1	1.53	57.5
HFC-R134a	0	1300	A1	0.99	0.91	1.02	44.5
HFC-R404A	0	3870	A1/A1	0.89	0.68	1.83	44.8
HFC-R407C	0	1650	A1/A1	0.99	0.99	1.64	53.6
HFC-R410A	0	1980	A1/A1	0.93	1.0	2.41	57.2
HFC-R507A	0	3850	A1	0.88	0.65	1.88	44.4
R717 (Ammonia)	0	<1	B2	1.04	6.90	1.55	93.3
R290 (Propane)	0	3	A3	0.97	1.71	1.37	44.2
R600a (Isobutane)	0	3	A3	1.01	1.66	0.53	40.0
R744 (CO2)	0	1	A1	0.63	0.85	9.0	72.0

New Trends in Refrigeration

- Introduction of VFD for compressors.
- Screw Compressors
- PHE/ Falling Film chiller +IBT
- Evaporative Condensers
- Liquid Ammonia pumping system
- Thermosyphon Oil Cooling system
- Chilled water pump automation with VFD
- Energy efficient motors - IE3
- Automation of the complete plant
- Low charge ammonia refrigeration system
- Co_2 refrigeration system
- Ammonia refrigeration chiller system for commercial air conditioning

About Project

Promoting Energy Efficiency & Renewable Energy in Selected MSME Clusters in India

To develop and promote a market environment for introducing energy efficiency and enhanced use of renewable energy technologies in process applications in the selected energy-intensive MSME clusters under GEF UNIDO BEE project.
The main objective of the project is to increase the capacity building of suppliers of EE/RE product and service providers

Desclaimer

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