Industrial Refrigeration for Dairy Industry

Date: 09 April 2018

Introduction

India is the largest milk producing country in the world, hence there is a need to efficiently handle & process the increased milk production to ensure that the farmers continue to get the remunerative prices and the consumers get the product at affordable prices. This has reinforced the need for technology up-gradation and use of energy efficient equipment in dairy industry. Energy is a topic whose importance has rapidly increased during the last few years. Not only the cost of energy has increased, but both, the world has become aware of the unsustainability of present mode of energy use and the effect of CO_2 emissions from our fossil fuel use.

The energy reduction through technology up-gradation and use of energy efficient equipment, in the following areas :

- Utilities (Electricity, Refrigeration, steam, water, compressed air)
- Processing and Product Manufacturing
- Milk Packaging

Electrical Energy

Electricity consumption contributes to the major costs in a dairy plant. The industrial electricity billing is normally done on the basis of actual units of electricity consumed plus the maximum demand charges. The maximum demand varies with the time of the day depending upon the various equipment in operation. Following are some of the technological upgradation, which can contribute for reduction in electrical energy consumption.

Refrigeration Compressors: Reciprocating

Most of the small and medium Dairy plants use traditional reciprocating compressors.

<u>Advantages</u> of reciprocating compressors:

- ➢ Off the shelf availability
- ➢ Relatively cheap in price than other types
- ➢ Suitable for small capacity requirements
- ➢ Easy in routine maintenance
- ➢ Suitable for high compression ratios
- ➢ Water cooled jacket in old designs

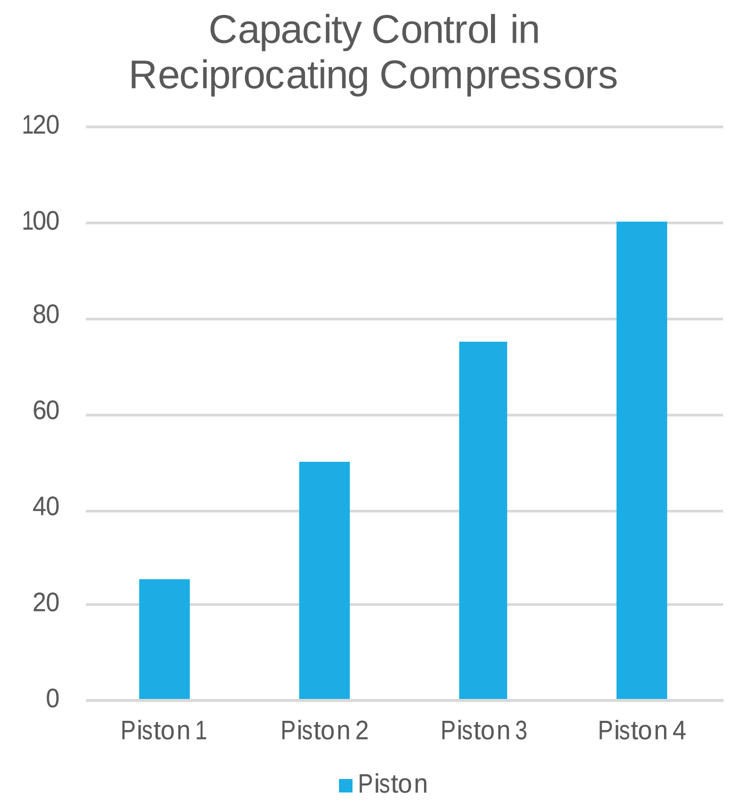
<u>Disadvantages</u> of reciprocating compressors:

- ➢ Very noisy operation
- ➢ High outlet temperature of compressed gas
- ➢ High oil content in discharged gas
- ➢ High frequency of maintenance
- ➢ Air cooled jackets in latest designs
- ➢ Lower COP compared to Screw
- ➢ Restricted pressure ratio

Capacity Control in Reciprocating Compressors:

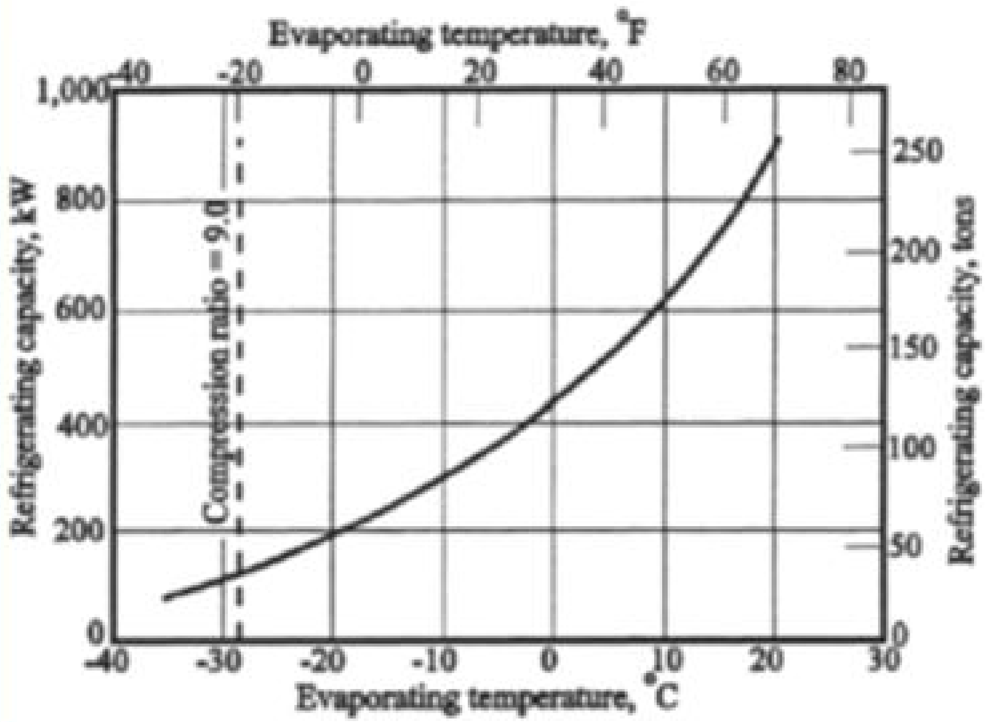
The capacity control of reciprocating compressors is as below:

- Piston determines the compressor capacity
- Pistons positions are determined by suction pressure PID control
- Slow system control due to 150s dead band
- System delays cause energy losses – lower temperature operations
- No linear capacity control possible – discrete control system
- This means compressor must run on 100% capacity for 76% load requirement, thus 24% loss

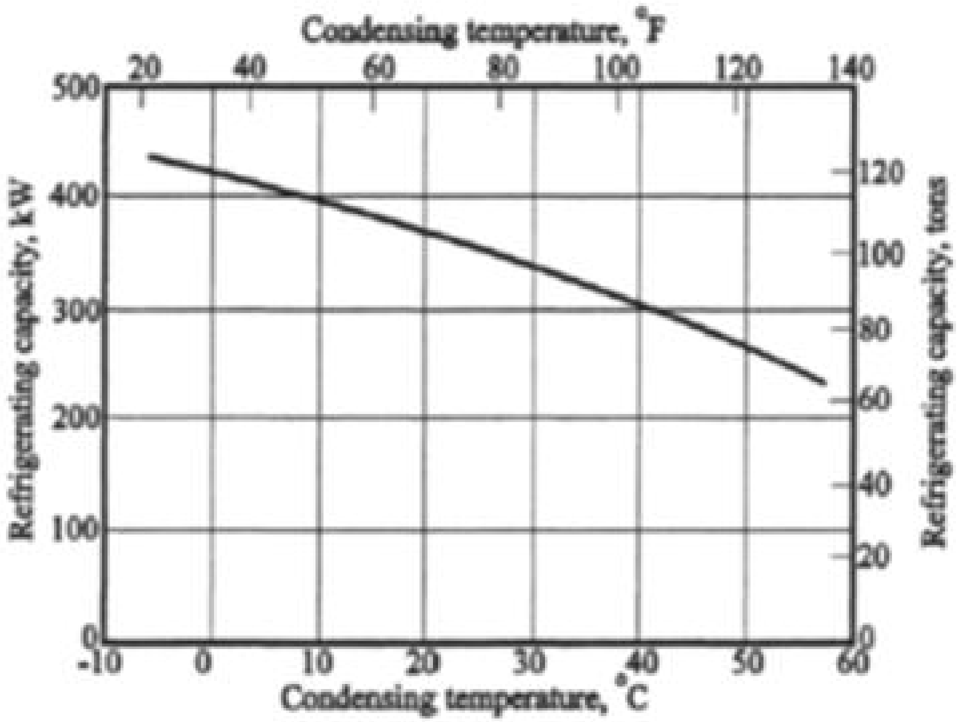


Performance of Reciprocating Compressors:

The effect of evaporating temperature on capacity:

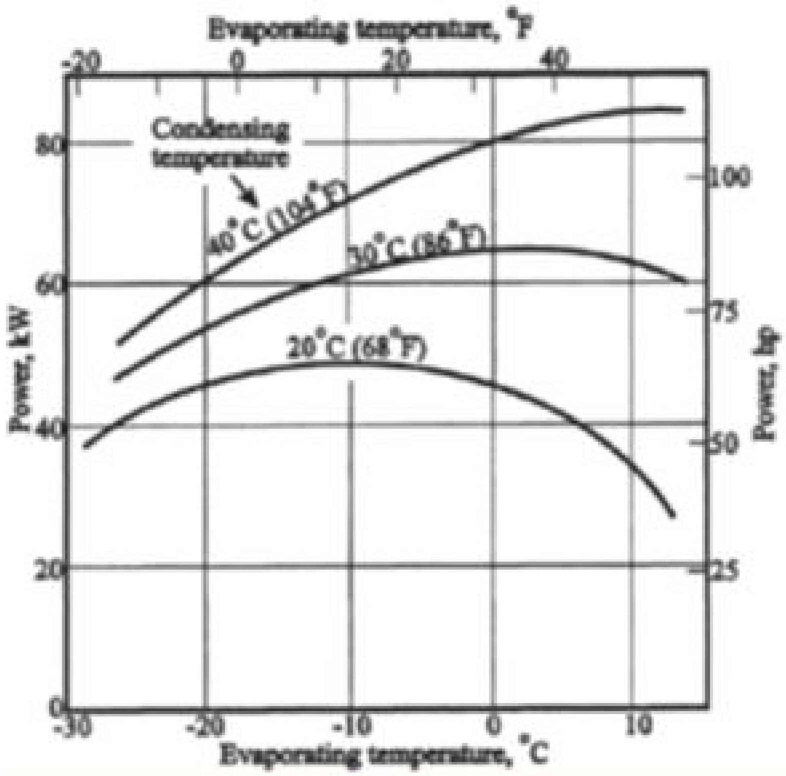


The effect of condensing temperature on capacity:

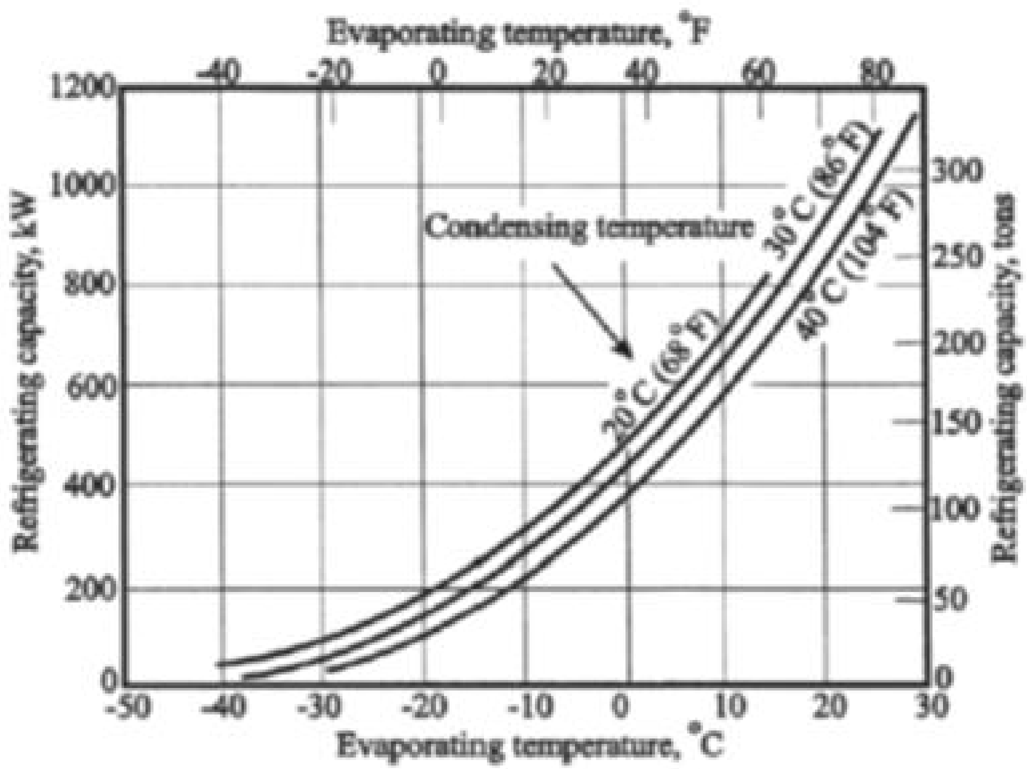


Performance of Reciprocating Compressors

The effect of evaporating and condensing temperatures on power consumption:



Combined effect of evaporating and condensing temperatures on capacity:



Refrigeration Screw Compressors

Refrigeration plant is the major utility, which consumes over 50% of the electrical energy of a typical dairy plant. There are two types: Single Screw and Twin screw compressors.
Twin Screw compressors are widely used and has several years of operation experience. It occupies a space alongside reciprocating compressors.

- **Twin Screw Compressors**

The compressors are the heart of the refrigeration system, which have undergone continuous improvements over the years. Screw compressors with economizer unit, offer the numerous advantages as compared to the conventional reciprocating type compressors. Listed few further

Refrigeration Screw Compressors

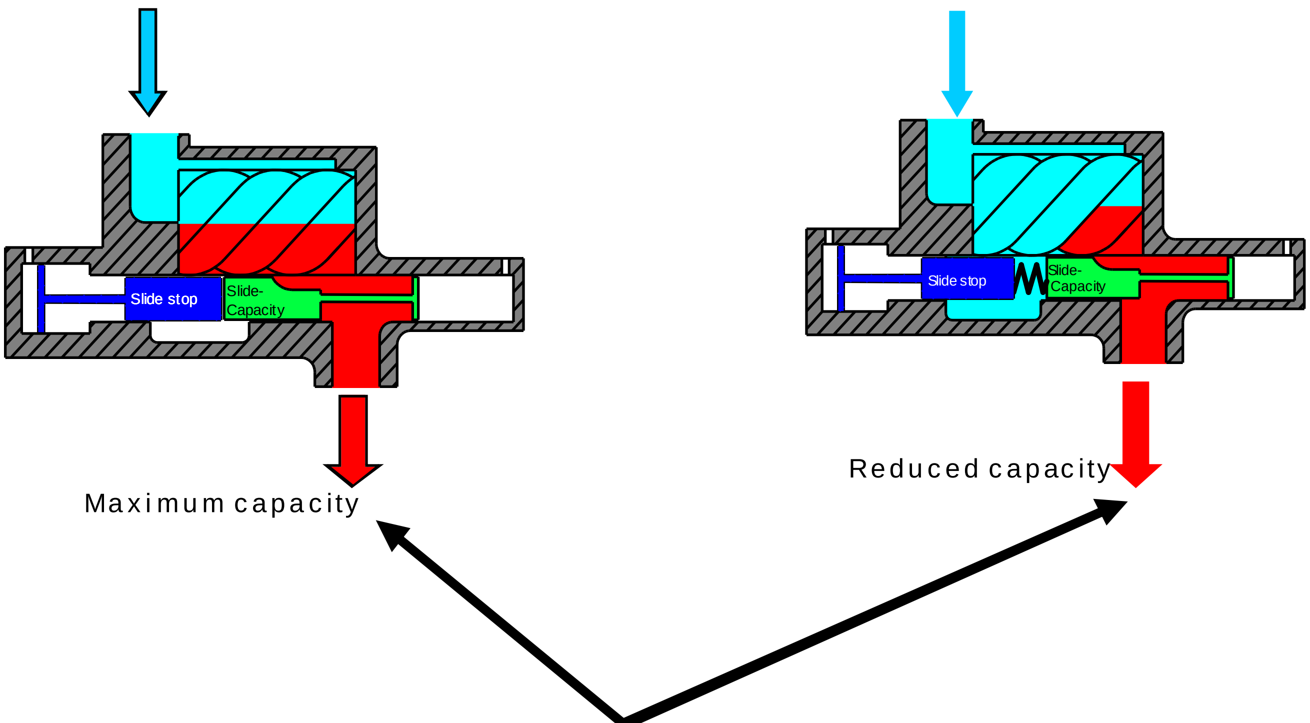
Screw Compressors Advantages:

- Higher COP
- Lesser power consumption
- Automatic Step-less capacity controls ensures accurate temperature/pressure control
- Variable Pressure ratio available to adapt varying ambient conditions
- Large swept volumes possible
- Pressure ratio of 20+
- Can operate with very low suction pressure
- Smaller size than reciprocating compressors
- Low noise operation
- Lower vibrations ensures smooth running
- Higher reliability
- Minimum maintenance requirement
- Longer life

Screw Compressor Disadvantages:

- Comparatively higher capital cost
- Lower COP for smaller capacities
- Trained service personnel required for maintenance of Screw compressors
- Separate Oil pump needed at lower suction temperatures

Capacity control in Screw Compressors



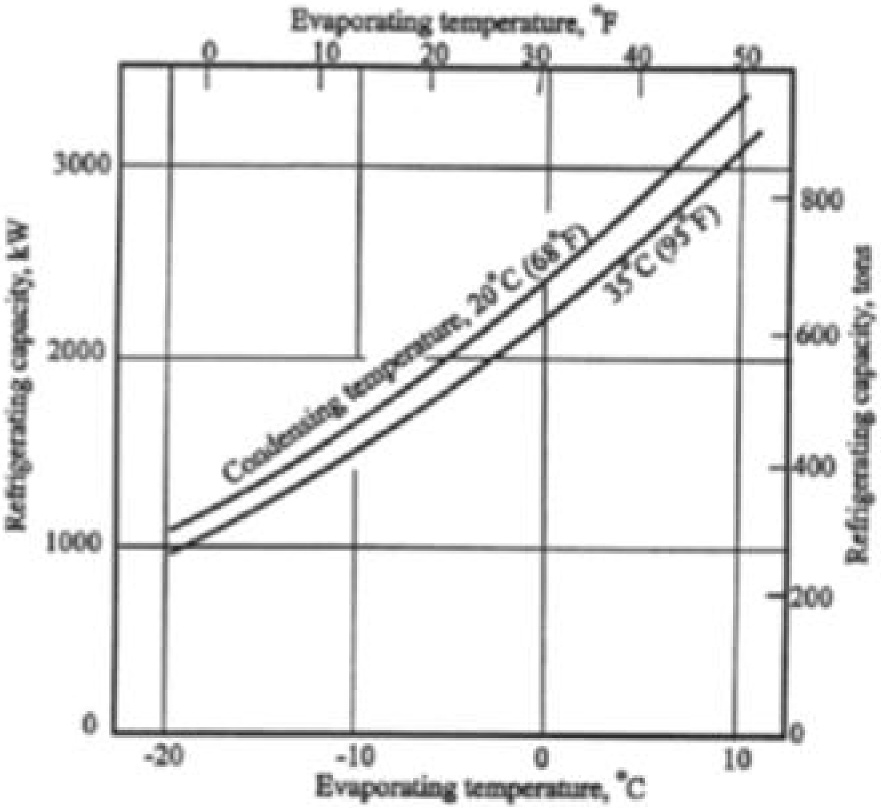
Active compression part

Slide valve Capacity control mechanism with operation of Solenoid valves used for capacity control

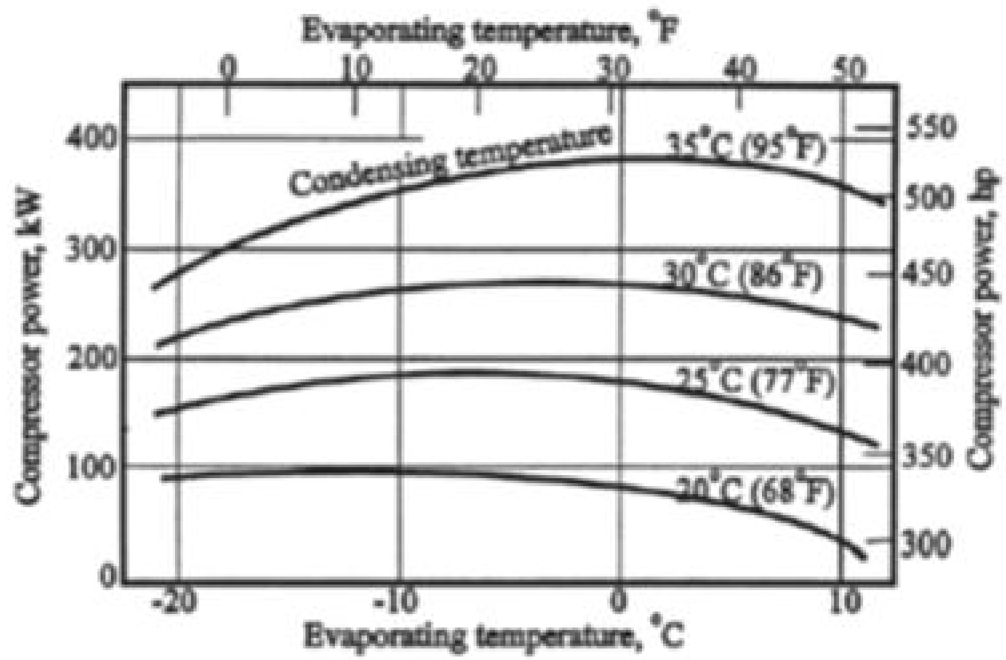
Step less Capacity control from 10% to 100% possible

Performance of Screw Compressors

The effect of evaporating temperature on capacity:



The effect of evaporating temperature on power consumption:

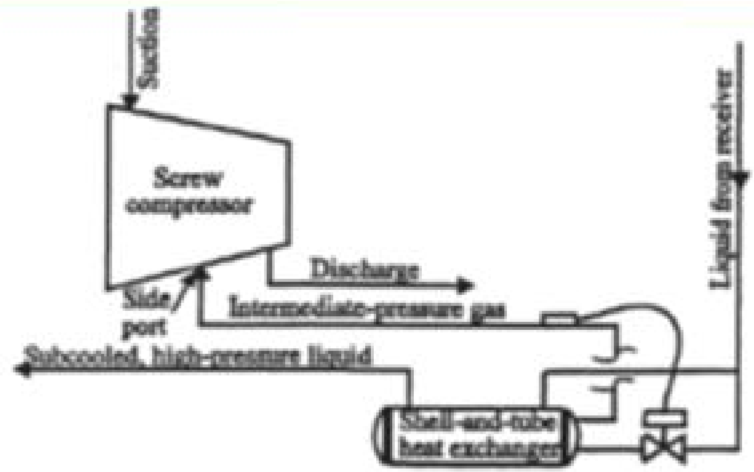


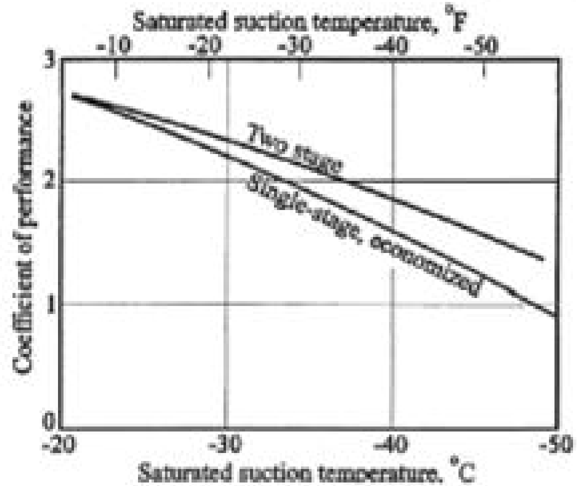
Economizer for Screw Compressors:

Economizers:

Twin-screw compressors are available with a secondary suction port between the primary compressor suction and discharge ports that can accept a second suction load at a pressure above the primary evaporator, or flash gas from a liquid sub-cooler vessel, known as an economizer.

A portion of the high pressure liquid is vaporized at the side port pressure and sub-cools the remaining high-pressure liquid nearly to the saturation temperature at the operating side port pressure. The effective refrigerating capacity of the compressor is increased by the increased heat absorption capacity of the liquid entering the evaporator. It improves COP of system by 3 ~ 5% in two stage economized system



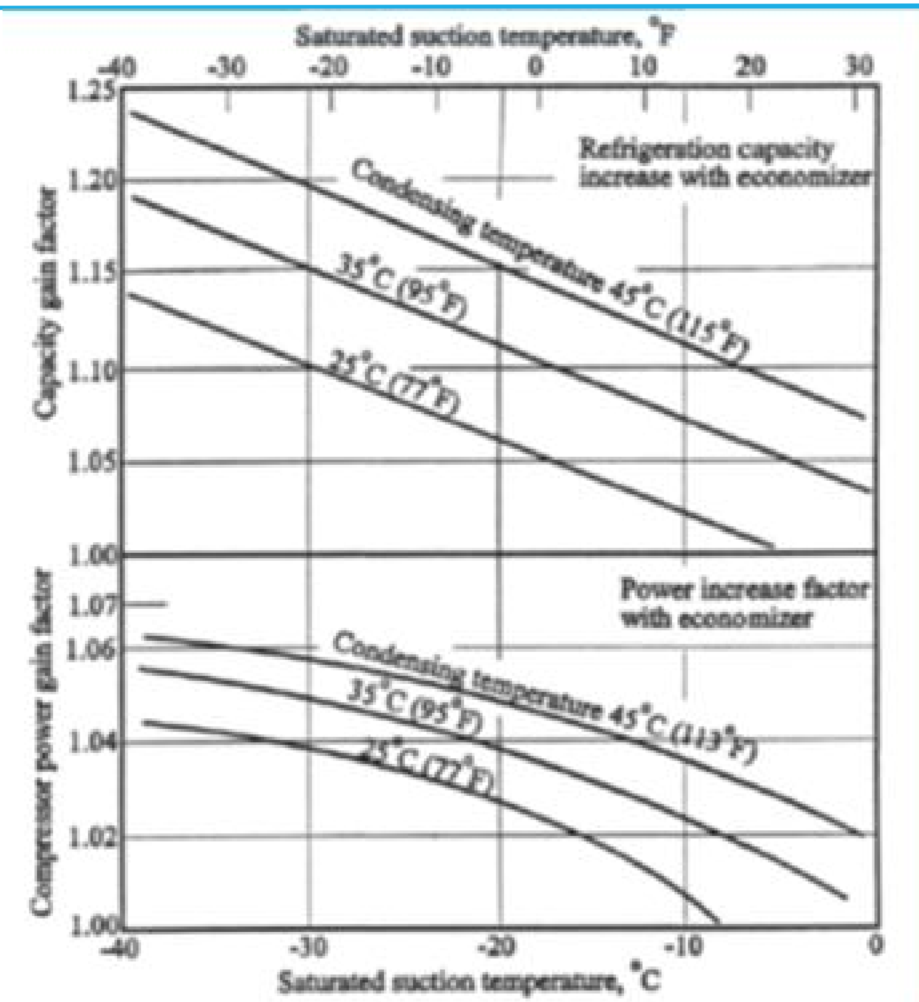


Economizer for Screw Compressors:

The overall effect of capacity gain and compressor power gain can be seen from the graph on the right hand side

In two stage economized systems, the capacity gain by use of economizer on its high stage compressor is considerably high while the power increase is relatively less and thus the combined improvement in capacity is fairly large.

The saving is effective when the compressor runs near to its full load capacity as the removal of flash gas diminishes at part load operations



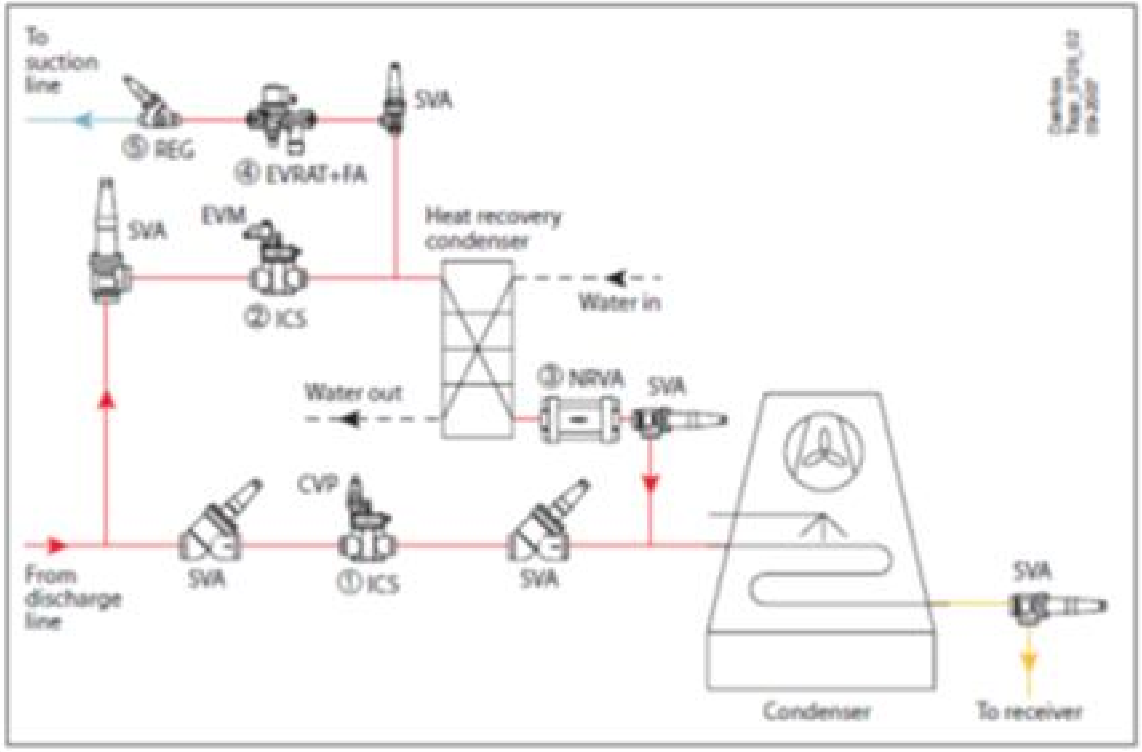
De-superheater Compressors to recover heat:

Desuperheaters:

The temperature of the discharge gas from compressors is generally 80 C and contain a good amount of heat within which goes to condenser for rejection.

Every dairy require hot water at 60~65 Deg C 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.

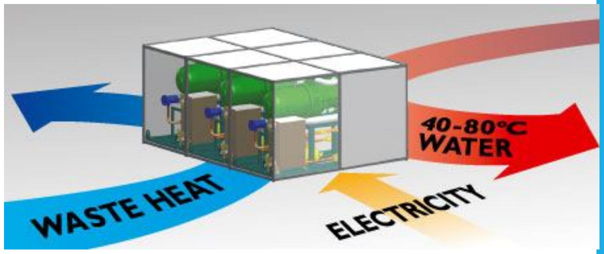
Save substantial amount of energy on account of electricity / fuel used in hot water generators



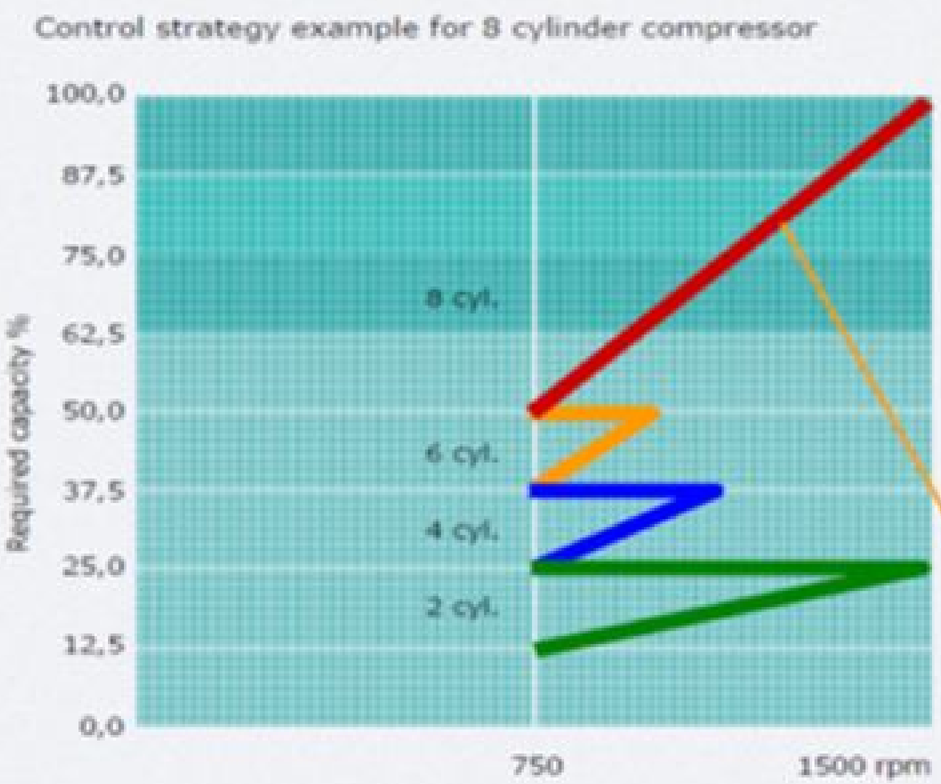
Heat pump:

Heat Pumps:

- Dairies can greatly benefit from harnessing the heat from Refrigeration system.
- Plant design can increase significantly the total performance, by adding NH3 heat pump technology
- Deliver hot water with 400 to 500% higher efficiency than gas or coal-fired boilers
- Reduce the amount of water consumption by reducing evaporation loss
- Single stage delivers the high temperatures up to 70 C
- Higher temperatures up to 85~90 C in Two stage systems
- COP 4+ as compared to 0.85 in fossil fuel fired boilers
- Becoming popular in Europe due to low ambient temperatures



Use of VFDs for Reciprocating Compressors

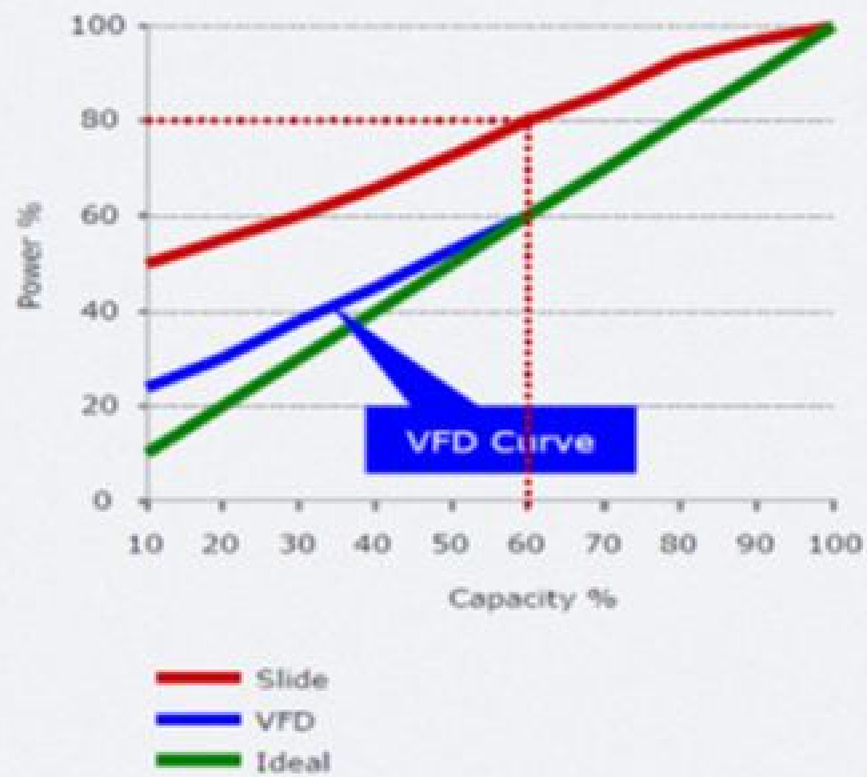


Reciprocating Compressor
– VFD Capacity Control

- VFD Compressor Capacity Control
  - Reciprocating
  - 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)

For a demand of 76% a capacity of 76% is required .
No Energy Losses

Use of VFDs for Screw Compressors:

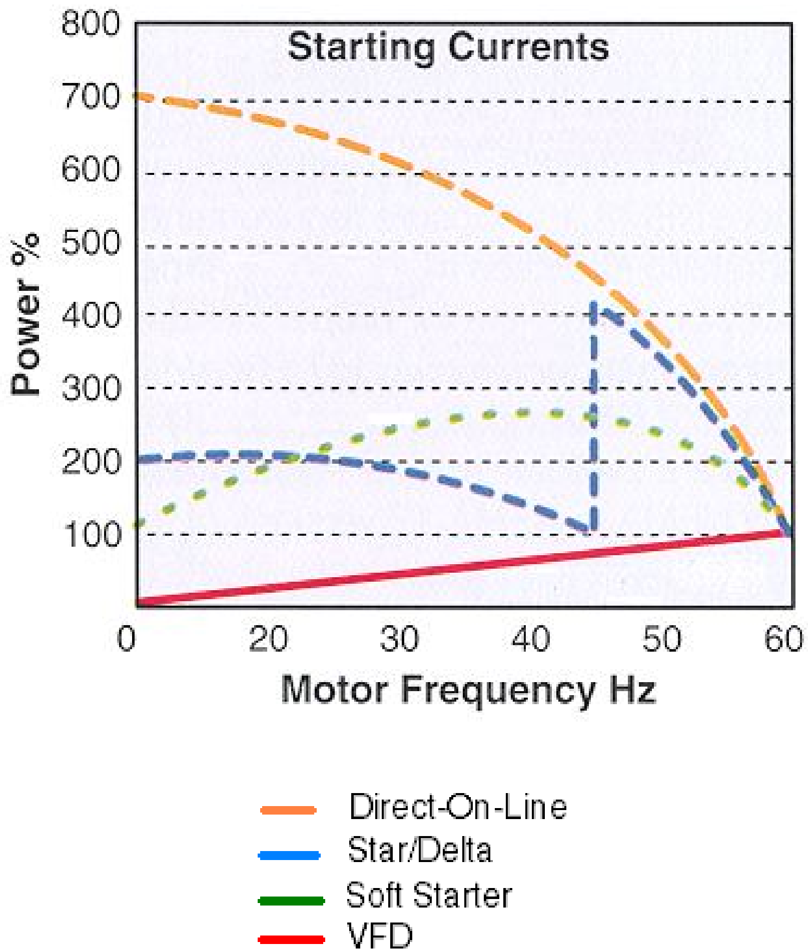


Screw Compressor
- VDF Capacity Control

- 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 temperature operation
  - Compressor COP is linear up to 60% of the capacity
  - Minimum speed must be maintained (Motor refrigeration, Oil pressure)

No Losses up to 60% of Nominal Speed

Use of VFDs for Screw Compressors:



Advantages of VFDs for Compressors:

- No in-rush current at start up
- Lower switchgear size
- Less power bill with lower Peak demand
- Smooth compressor start
- Low wear and tear of compressors
- Reduction in installed DG set capacity
- Specially Danfoss VFDs run with normal motors
- Better motor protection and safety

Use of VFDs for FDCs, Pumps:

Use of FDCs for other motors in plant:

- The power consumed in FDCs / FCUs is reduced by 50% with speed reduction of 20%
- Cooling Tower Fans
- Evaporative Condenser Fans
- Chilled water pumps
- Glycol pumps

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Sample saving calculation for 30KW Drive

The following example illustrates the energy saving potential of 30 KW variable speed drive for chilled water pump application, instead of controlling flow by throttling valve:

Flow	Power consumption (KW)		Energy consumption per year (KW)		Energy cost per year (Rs)		Yearly cost saving by VFD (Rs)
	Controlled by throttling valve	Controlled by VFD	Controlled by throttling valve	Controlled by VFD	Controlled by throttling valve	Controlle d by VFD	
90%	28.17	24.28	246769	212692	987076	850771	1,36,305/-
80%	26.17	18.54	229249	162410	916996	649641	2,67,355/-
70%	25.62	14.04	224431	122990	897724	491961	4,05,763/-
60%	24.71	10.61	216460	92943	865840	371774	4,94,066/-
50%	24.03	8.01	210502	70167	842008	280670	5,61,338/-
40%	23.56	6.08	206385	53260	825540	214043	6,11,497/-
30%	23.33	4.73	204371	41434	871484	165739	7,05,745/-

Power saving with Energy Efficient Motors

Electric motors have been the main providers of motive power for the industry. Now a days, high efficiency AC induction motors are available. The efficiency level of these motors is about 3% higher than that of the standard AC induction motor.

An economic analysis for a 15 KW motor is given below, which I am sure will certainly attract the end users to go for high efficiency motors :

	Standard Motor	Energy Efficient Motor
Price (Rs.)	28,700/-	34,620/-
Price Premium (Rs.)		
Efficiency (%)	89%	91.8%
Annual operating hours (Hrs)	8000	8000
Energy cost (Rs./KWH)	7.5	7.5
Annual Energy cost (Rs./Annum)	10,11,236/-	9,80,392/-
Annual Energy Saving (Rs./Annum)	-	30,843/-
Payback Period (Years)	-	1.12

Refrigeration Plate type Evaporators & Condensers

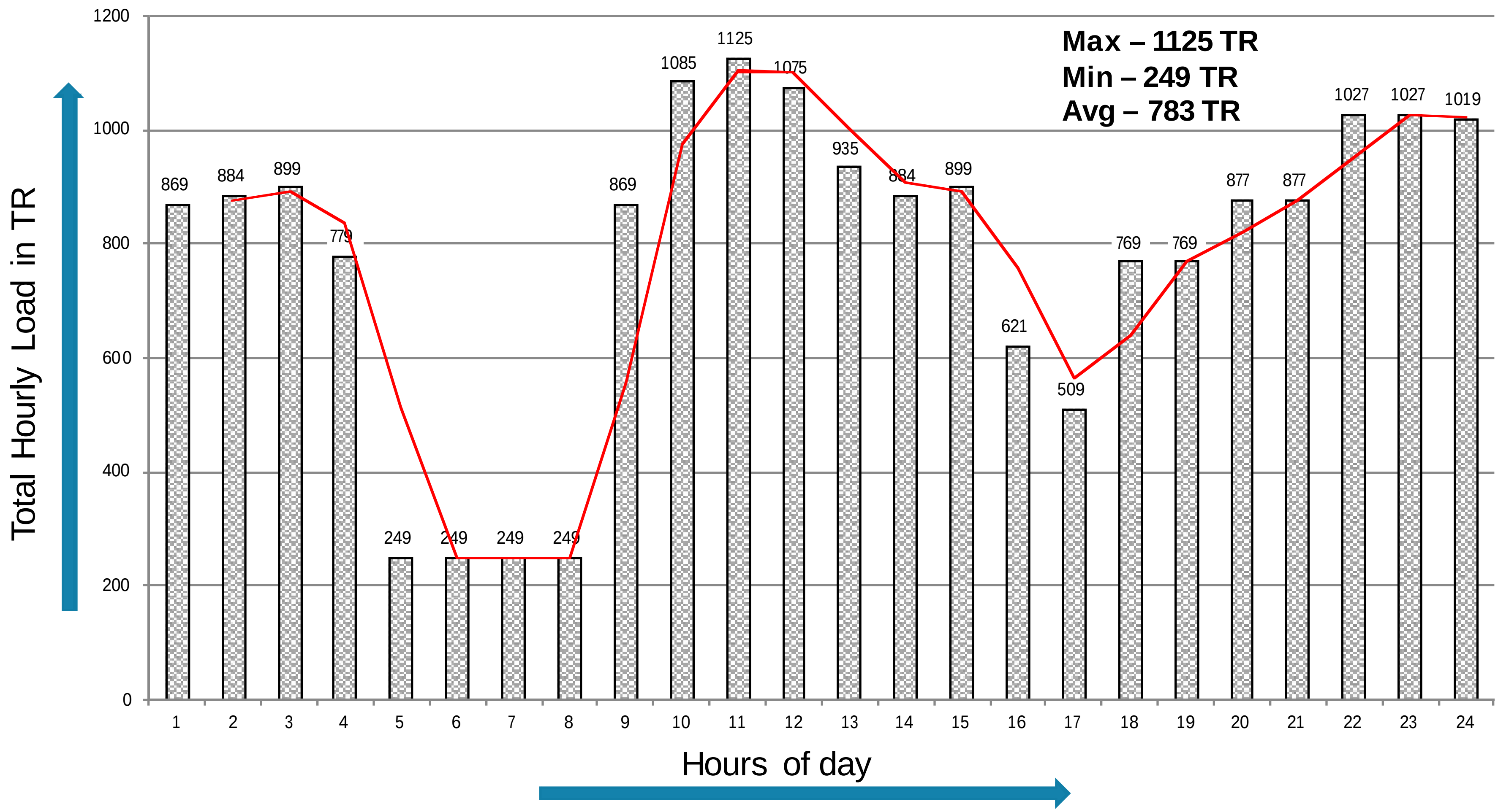
PHE Type condensers:

Plate type Heat Exchanger (PHE) condensers are widely available, which are very compact in design due to higher heat transfer coefficient and consume lesser power and water. The capital cost of the PHE type is also lower than the VST type condensers.

PHE type Pre-chiller:

A combination of PHE type pre-chiller and conventional IBT is presently being incorporated in chilled water system. The chilled water returning from the process is pre-chilled to about 2 C before entering the IBT. Due to the higher heat transfer coefficient provided by PHEs, the requirement of ice bank coil length comes down, which results in smaller IBT size thereby saving the land and lesser capital cost, as compared to conventional system of same capacity.

Typical Hourly Refrigeration Load - Chilled water Histogram



Advantages of Ice Silo over traditional IBT system

Ice Silo is a vertical cylindrical vessel with Stainless Steel Spiral coil inside acting as evaporator and accumulates upto 40 ~ 50 mm Ice Hygienically on it for safe use in process industries like Dairy to consistently supply chilled water at near zero temperature for critical processes

Sno	Ice Silo	Ice Bank Tank system
1	Very small foot print (area of installation)	Large foot print (area of installation)
2	Outdoor installation, no building required	Indoor installation, building required
3	Made from SS304+ plates and tubes	Made from Mild Steel plates and tubes
4	Supplied pre-fabricated, less time for installation	Fabricated at site, more time for installation
5	No corrosion	Prone to corrosion
6	No tube failure, no NH3 leakage, very safe	Frequent failure of tubes and NH3 leakage
7	No choking & no failure of strainer, valves	Frequent choking & failure of strainer, valves
8	Advanced PLC based precise ice thickness controller	Traditional ice thickness controller
9	1 no 0.85 kw motor for agitator, huge power saving	8 nos 5.5 kw motors for agitators
10	No accumulation dust, dirt and microbes in water	Accumulation of dust, dirt, microbes in water

Power Saving on account of agitator motor

Description	UOM	Ice Silo	IBT
Agitator motor full rpm	KW	5.50	22.38
1455 rpm	Amp	10.50	
Agitator Motor with lower rpm (VFD)	KW	0.90	
735 rpm	Amp	3.80	
24 hours running power	KW	98.88	537.12
360 days operating power	KW	35597.00	193363.00
Saving in operation power	KW	157766	
Power tariff considered	Rs./KWH	9	
Savings in power cost in a year per Ice Silo	Rs.	1419898	

Power Saving on account of tariff plan (illustration)

Description	UOM	W/o Ice Silo	After Ice Silo	KWH Saving	Tariff Rs.	Saving Rs.
Compressor motor power	KW	250	250			
Full load - 06 am – 09 am	Hrs	3	0	675	8.59	5798
Part load - 09 am – 12 noon	Hrs	3	0	506	9.39	4753
Part load - 12 noon – 06 pm	Hrs	6	4	113	8.59	966
Full load - 06 pm – 10 pm	Hrs	4	4	0	9.69	0
Full load - 10 pm – 06 am	Hrs	8	8	0	6.09	0
Total saving per day	KWH	6000	4000	1294		11518
Working hours in a year	Hrs	340	340	340		
Total saving in a year	Rs./Yr					3916226

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Ice Silo Installation Photographs

Low charge Ammonia system: Example

The dairy plants within the city limits need to reduce the Ammonia volume in the entire refrigeration system

- It is a low charge ammonia system installed in 2016 in a large dairy plant situated in crowded area of Delhi city
- This is 330TR Glycol chilling system
- Traditional refrigeration system would require approx. 3800~4000 Liters Ammonia
- The skid has 300 Liters of Ammonia
- It has de-super-heater installed on top to generate hot water for dairy use

Efficient defrost for optimum energy

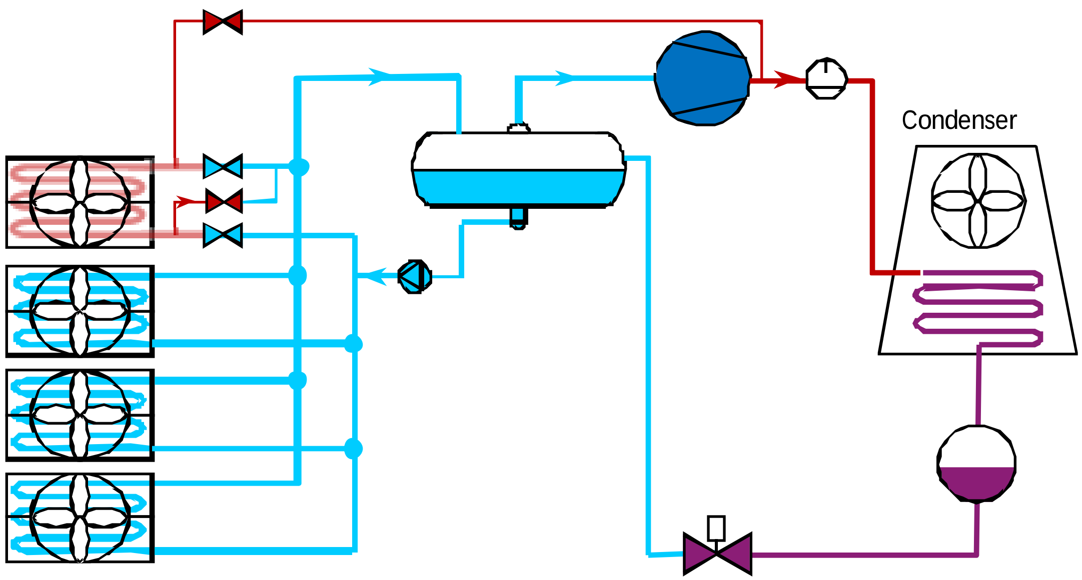
Air cooler totally covered with ice

In-efficient defrosting of an aircooler

”Clean” aircooler

Appropriate defrost mechanism

- Implement proper defrost cycle in place
- It keeps surfaces clean to have maximum heat transfer from process to refrigerant
- It ensures the room / product temperature is achieved
- It improves total cycle efficiency due to optimum running of refrigeration system
- It protects equipment against damage due to hard expanded ice within tubes / trays etc.



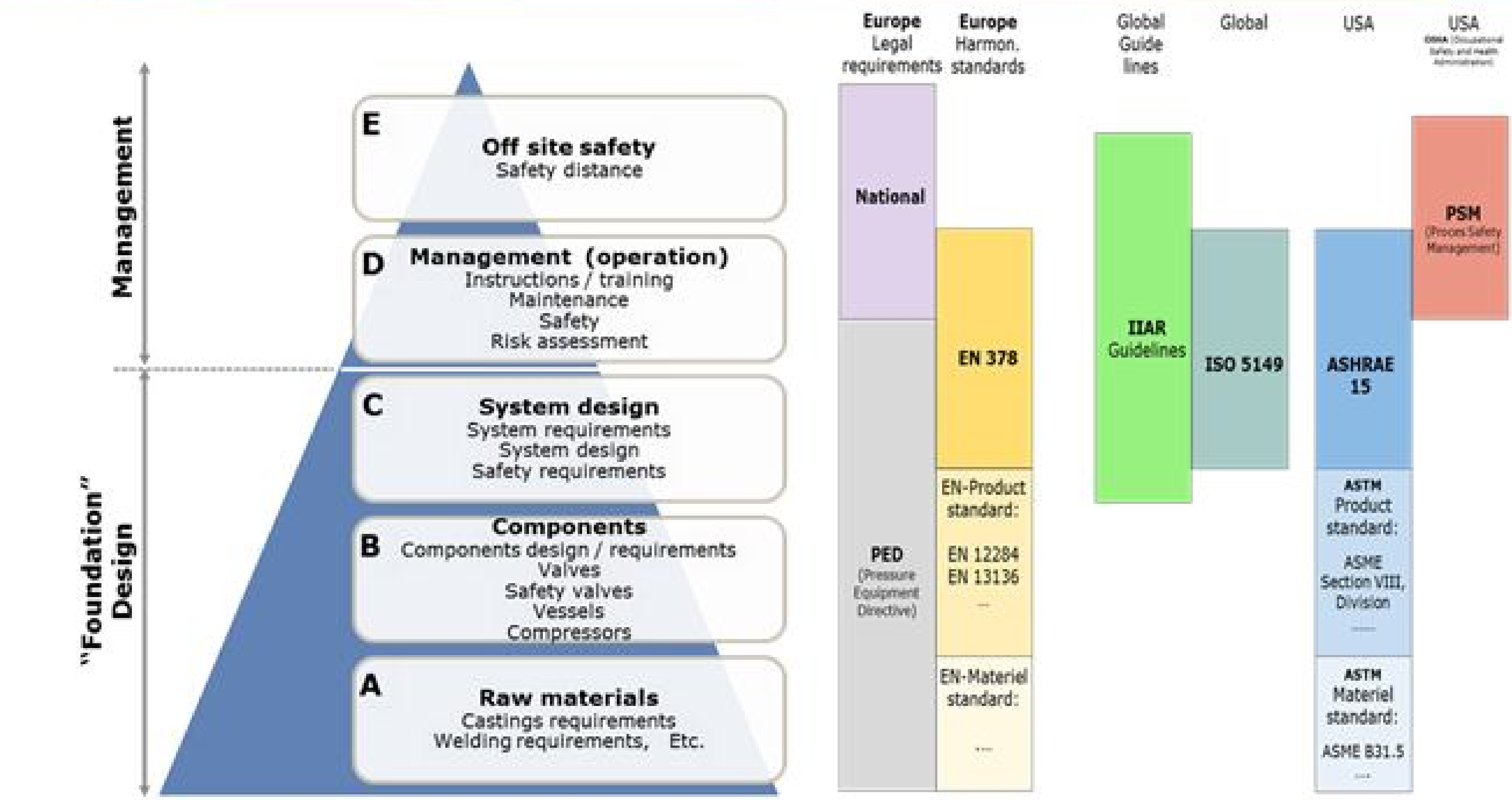
Hot Gas defrost Cycle

Safety in ammonia systems

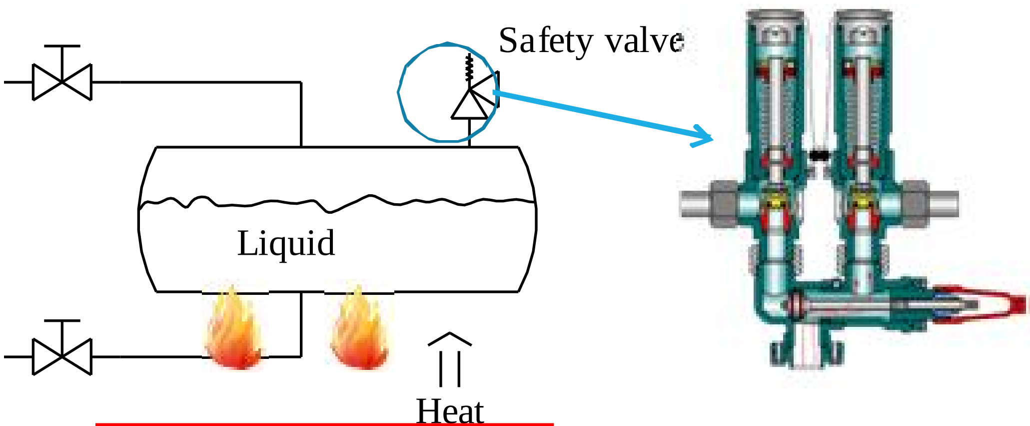
Ensure safety in Design, regulation and operation

- Codes EN78, ASHRAE15, ISO 5149 are followed while Designing the system
- Install safe and reliable equipment
- "Code of practice" (IIAR Guidelines) are implemented for operation
- Good and safe control strategies while designing the system
- Clear Operation sequence instructions / SOPs are in place
- Safety management is defined
- Scheduled maintenance of equipment as per manufacturer's recommendation

Safety in ammonia systems



Safety in ammonia systems: EN3136: 2013 Dual relief valves



$$Q_{md} = \frac{3600 \bullet \Phi \bullet A_{surf}}{h_{vap}} \text{ kg/h}$$

Φ Density of heat flow; 10 kW/m^2

A_{surf} External surface; m^2

h_{vap} Heat of vaporization, at 1.1 x set pressure; KJ/Kg

Q_{md} Required capacity of safety valve; Kg/h

Safety in ammonia systems: Liquid hammer

Liquid Hammer is a common used name for various phenomena's that create pressure peaks in e.g. refrigeration systems.

Liquid fluids (single phase):

- **Deceleration of liquid flow**: Instantaneous change in the flow velocity in liquid fluids may create pressure peaks, propagating through the pipeline system as high speed waves (pressure surges, liquid hammer)

Two-phase fluids (liquid and vapor):

There are two distinct ways of forming shocks in two-phase fluids Mechanical and Thermodynamic.

- **Vapor-propelled liquid slug:** This mechanical form can arises when a gas flow is initiated at high velocity accelerating liquids, e.g. when a large valve is opened with high pressure.
- **Condensation-induced shock:** This thermodynamic form can arises when large reduction in volume of vapor that condenses due to heat transfer between the refrigerant vapor in the presence of subcooled liquid.

Vapor-propelled liquid slug and condensation-induced shock can work together during a hydraulic shock event.

Safety in ammonia systems: safe oil drain

Oil drain is often reported to be responsible for significant ammonia releases.

Safe oil drain method

- The 2 additional shutoff valve ensure that the “worst case release scenario” for draining oil are limit to be less or equal to the collector size
- Without the shutoff valves; the “worst case release scenario” for draining oil are limit to be less or equal to the receiver size
- The shown method is also safe when draining oil at higher pressure

Safety in ammonia systems: safety valves

Correct sized safety valves are essential in obtaining the overall safety of a refrigeration system during operation, standstill (incl. fire)

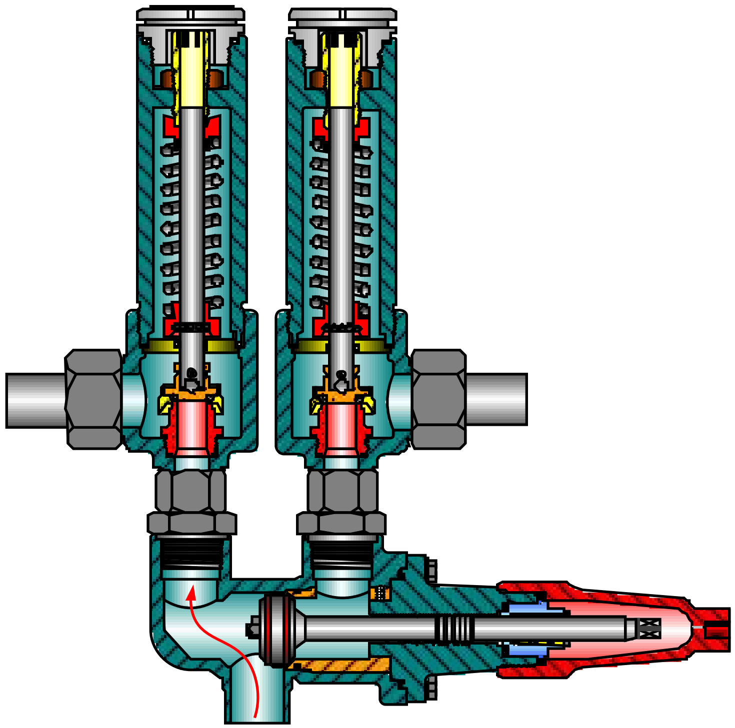
- Safety valves ensure that the pressure in the vessel **never will exceed a critical level**
- According to international standards, safety valves shall have a capacity that can release the pressure, when the vessel is exposed to an **heat flux on 10 kW** *)
- **Experience shows that correct sized safety valves protect the vessel, even in the case of an extensive fire.**
- Capacity calculation with up- and downstream lines needs to be conducted, to ensure correct operating safety valve.
- It is essential that safety valves are inspected and tested regularly.
- If no national requirements exist, EN 378-4 / ISO 5149-4 specify:

Inspection (leaks): Yearly

Test / replacement: Every 5 year.

Safety in ammonia systems: safety valves

Dual safety relief valve system fulfills all requirements



Safety in ammonia systems: conclusion

Ammonia is a proven and safe refrigerant

- 150 years experience in the industry
- Ammonia is the preferred refrigerant in IR globally
- High system efficiency
- Easier maintenance
- Safety is essential - as with **all** other refrigerants

There are many methods to reduce the risk

- Reduce the refrigerant charge amount
- Design system with high safety requirements
- Conduct risk assessment and perform mitigations actions
- Ensure prober operation and maintenance


Thank You