Heat Pump Operational Constraints in High Ambient Temp (India)

Medors Renewable Energy

- Medors was incorporated in 2011.
- Since then, the company has successfully operated in the refrigeration including heat pump and solar PV sectors.
- The company’s manufacturing units are in Noida and Kundli, Sonipat.
- Our heat pump systems are installed in both commercial and residential sectors in India.
- The company has successfully coupled solar power plant and heat pump installations, which results in greater synergies for the end consumer and is also better for the environment.

Medors Renewable Energy

- Some of our most notable commercial installations include Sir Ganga Ram Hospital (Rajendra Nagar, Delhi), Ayushman Hospitals (Sector 10 & 12 Dwarka, Delhi), Regenta Central Antarim Hotel (Ahmedabad), Radisson Blu Hotel (Dwarka, Delhi).
- Whereas, in the residential sector, we are proud to have installed our heat pump systems in the residence of Late Shri Arun Jaitley (Vasant Kunj, Delhi)
- We are a research intensive company and we have collaborated with numerous research institutes.
- We have a strong and motivated team of Doctors and Engineers with expertise in CFD, Heat Transfer and Fluid Engineering.

Variation in Weather….

- In North India, extreme variation in temperature is prevalent.
- For instance, the average temperature in New Delhi is 24.6 degrees celsius.

- However, With an average of 33.0 °C | 91.3 °F, June is the warmest month. In January, the average temperature is 13.5 °C | 56.3 °F. It is the lowest average temperature of the whole year https://en.climate-data.org/asia/india/delhi/new-delhi-30/

Heat pump at high ambient conditions and its Challenges

- Superheat Management
- Compressor improper lubrication.
- Compressor discharge temperature increases.
- Balancing the system and Refrigeration cycle
- Specific volume at the inlet to the compressor increases
- Wide variation in Loads, due to unpredictability of ambient conditions
- Compressor Efficiency decreases
- Refrigerant Selection.
- Controls

Step by Step Design Considerations….

1. Refrigerant Selection
2. Compressor Selection / its controls
- Load Variation
- Motor ability to withstand high temperatures
- Ability to withstand harsh conditions. Some liquid return and loss of oil.
- Oil Selection
1. Evaporator Design / Its control
- Optimal Superheat
- Ensuring Volumetric Efficiency

Continued….

4. Condenser Design / Its Control

- Optimal Subcooling
- Optimal control of Discharge Temperature

5. Expansion Valve Selection and Evaporator Effect

- Operation in wide load conditions
- Avoid Overflooding or Starvation of Evaporator
- Ensure Liquid Refrigerant does not get trapped in Condenser

6. Effective Piping / Controls (Not having flash tank, liquid separator)

Refrigerant Selection…..

- Identification of Design Conditions
- Latent heat of vaporization: Should be as large as possible so that the required mass flow rate per unit cooling capacity will be small
- Critical temperature should be clearly higher than the targeted condensation temperature.
- Compression Ratio should be as low as possible
- Discharge Temperature at various condensing conditions
- Low GWP, ODP, Toxicity and Flammability
- Trained Personnel, ease of availability of ancillary equipment such as expansion valves etc

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- **Specific heat**: Liquid should be small so that degree of subcooling will be large leading to smaller amount of flash gas at Expansion Valve inlet. **Vapour specific heat** Should be large so that the degree of superheating will be small
- **Thermal conductivity:** Thermal conductivity in both liquid as well as vapour phase should be high for higher heat transfer coefficients
- **Viscosity:** Viscosity should be small in both liquid and vapour phases for smaller frictional pressure drops
- **Operational Pressure** ideally should be higher than the atmospheric pressure

Best Options…..

- R290 stands out for medium temperature application. It has high volumetric heating capacity.
- R600 stands out for extremely high temperature required in commercial sectors.
- R600 presents relatively manageable pressures at high load conditions.

Classifications	Name	ODP	GWP	Flammable	Toxic	Available
Medium Pressure	R444B	0	295	No	No	Yes
	R290	0	0	Yes	No	Yes
High Pressure	R32	0	677	No	No	Yes
	R1234yf	0	4	Yes	No	Yes
	R1234ze	0	6	Yes	No	Yes
	R600	0	20	Yes	No	Yes

Compressor Selection

- Ability to work under high compression ratio from time to time..
- **Oil Selection and Oil Management**. Lubrication conditions to be monitored
- Wide operation envelope
- **Some refrigerants like R600 have a threat of wet compression:** The consequence of the overhanging shape is the possibility of refrigerant condensation during compression ("wet compression") which can lead to compressor damage. Compressor heat loss also enhances the threat of wet compression.
- Therefore ability to withstand some liquid return and design to be robust.
- Internal Motor Protection either to be included or managed through controls.
- Compressor Sizing and volumetric Heating capacity to be weighed against **Investment and Refrigerant Selection.**

Compressor Lubrication and Effect of Overheating….

- Effect of high suction pressure and high suction temperature results in compressor overheating.
- This causes lubrication properties to change due to lower viscosity in the oil sump. At this stage it is vital for rotor bearings that the designer takes measures to ensure effective operation.
- The decrease of oil sump viscosity and increase of load with the increase of ambient temperature, leads to decrease in the minimum oil film thicknesses of main bearing, sub bearing, and eccentric bearing in the compressor.
- Options of Mineral Oil and Synthetic Oil are readily available. The suggestion of their properties and overall system operation need to be considered.

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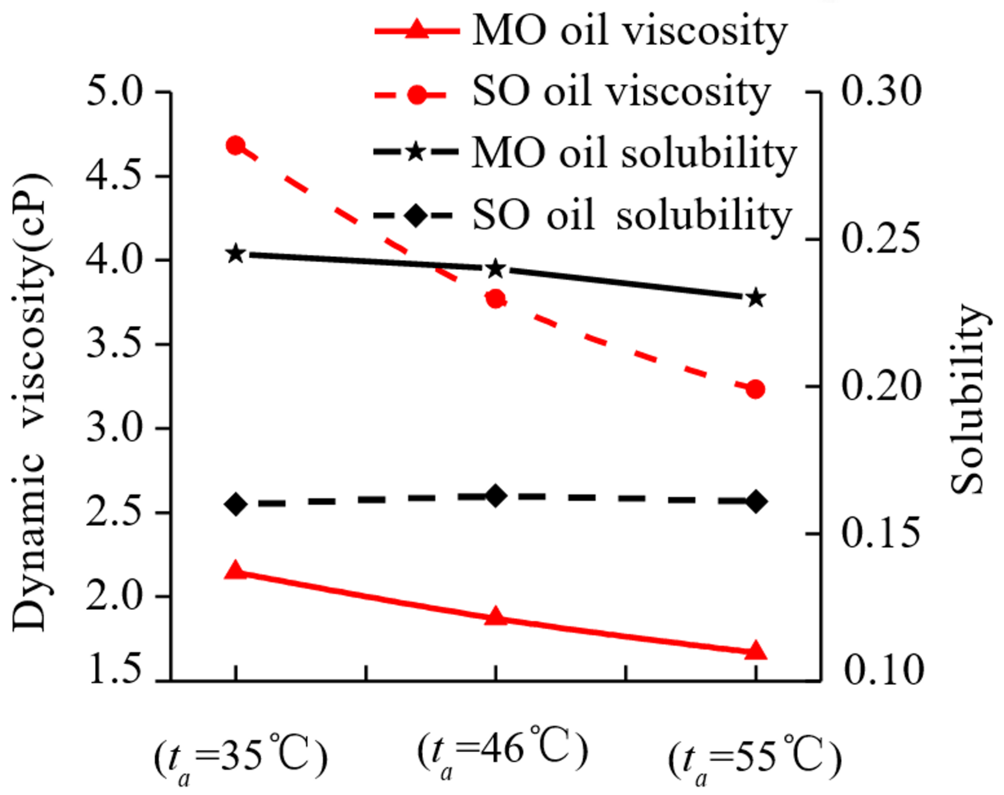
- Oil sump viscosities of **SO (3.2cP ~ 4.7cP) higher than MO (1.6cP ~ 2.9cP) under any condition.**
- Viscosity of MO and SO both decrease with the increase of ambient temperature from 35℃ → 46℃ → 55℃ condition.
- Synthetic Oil is preferable due to higher viscosity.
- When the evaporator operates above 35C temperature then the condensing and discharge temperature of the compressor will be at 130C and above. At this temperature mineral oil and synthetic oil can struggle. **Synthetic engine oil** can be a good option which can withstand upto 400C



Refrigerants	@35	@46	@55
R410A	84	96.2	111.9
R32	98.3	112.7	128.2
R22	79.5	98.2	112.0
R290	73.8	84.1	96.2

Evaporator and Expansion Valve…..

- Best evaporator performance varies as per the refrigerant but as a general rule low superheat is shown to be most efficient.
- Flooded Evaporators are shown to have good performance metrics. They ensure better oil return and also ensure lower discharge temperature.
- Expansion valve for superheat control can be categorised as follows.

1. Hand (manual) expansion valves
2. Capillary Tubes
3. Orifice
4. Constant pressure or Automatic Expansion Valve (AEV)
5. Thermostatic Expansion Valve (TEV)
6. Float type Expansion Valve a) High Side Float Valve b) Low Side Float Valve
7. Electronic Expansion Valve

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- Generally capillary tube or TEV's is used in domestic freezers, AC's and can be considered to be popular amongst designers.
- This poses huge issues for the operation of the heat pump.

Evaporator Load Increases

- In this scenario, the compressors calls for more refrigerant. Inability to supply will lead to starvation of the evaporator, create efficiency and operation related issues due to high superheat.
- The corrective action will require need to supply more refrigerant. Inability to do so will result in condenser getting flooded with liquid refrigerant.
- Reynolds number decreases and as a result, the heat transfer coefficient of the evaporator decreases. This will cause poor heat transfer as well as create operation difficulty.

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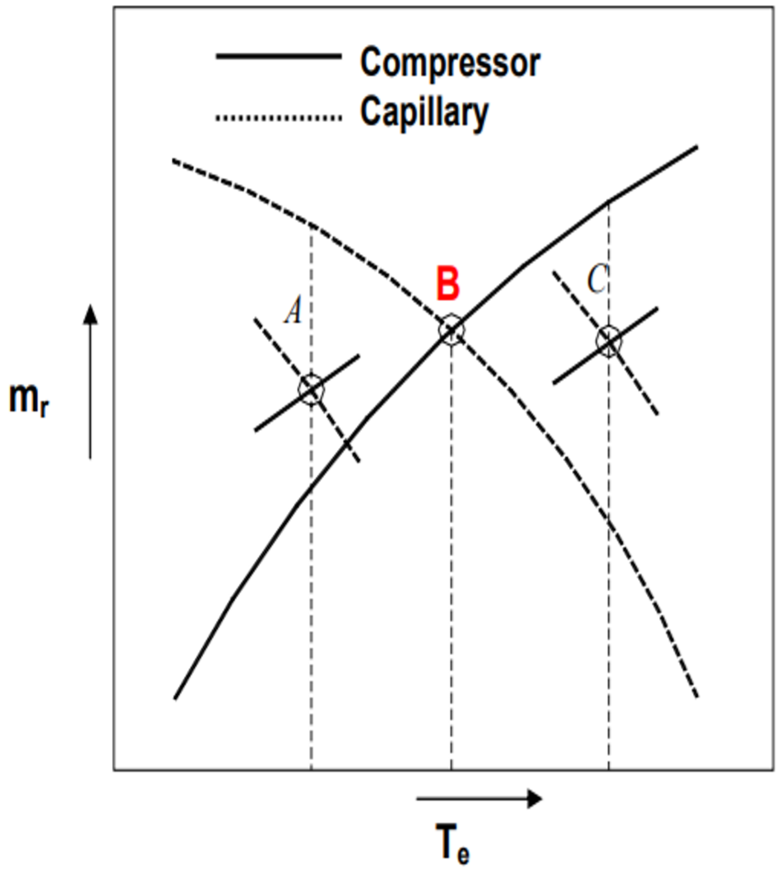
Evaporator Load Decreases

- This leads to accumulation of liquid refrigerant in the evaporator causing flooding of the evaporator. This may lead to dangerous consequences if the liquid refrigerant overflows to the compressor causing slugging of the compressor.
- Critical charge can be used as a means whereby worst case scenario will result in evaporator being full of liquid refrigerant. However still is not ideal.



Superheat and Discharge Temp…

Flooded or 'ZERO' Superheat

- Close to zero superheat values for the refrigerant leaving the evaporator are to be preferably maintained.
- Mostly the oil return to the compressor is also improved, as the oil is typically accumulated in the evaporator superheated section.
- Also, the oil viscosity is reduced with the superheat reduction due to the fact that more refrigerant is diluted in the oil at lower superheat values, and to a smaller degree, due to a saturation suction temperature increases which can also improve COP.
- Discharge temperature can also be controlled.

TEV and EEV

- Compared to capillary tubes and AEVs, a TEV is more expensive and proper precautions should be taken at the installation. For example, the feeler bulb must always be in good thermal contact with the refrigerant tube.
- However still in applications requiring close control of superheat this proves to be inefficient. In heat pump operation load can vary in minutes. TEV's fail to offer that safety and functionality.

EEV

- Stepper motor expansion valve is shown to have the greatest control and offer most efficient operation. It opens and closes the valve with a great precision giving a proportional control in response to temperature sensed by an element.

Condenser Design and Challenge of Subcooling…..

- Subcooling is desired to ensure effective operation of the EEV. However it can result in higher condensing pressure.
- Higher condensing pressure will result in higher discharge temperature and cause overall strain on the compressor and the system.
- In this case careful consideration has to be made when designing heat exchanger.
- It can be beneficial to design a condenser with a limited subcooler section.
- On occasions there is an option to instill a subcooler if the client demand allows. This can be where rinsing of the dishes or any other requirement of low grade heat. However the scenario is different because the heat is being used.

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- The **vapour quality** at the evaporator if is high. Can actually be beneficial for the overall system.
- In high ambient conditions the load is high so for same evaporator area more heat exchange need to occur.
- If vapour quality is high at the evaporator inlet. Then the evaporator surface area can be used more efficiently.
- Due to the reasons mentioned above **liquid separator or flash tank** can be inefficient for the operation of the heat pump. This should be avoided wherever possible.
- There is a balance to be found between optimal subcooling to ensure effective operation of the EEV and at the same time ensure that the evaporator area can be managed and used efficiently.

Capacity Control Strategies….

- In heat pump designing the biggest challenge faced is to avoid oversizing the system and yet cope with high ambient conditions that may be encountered occasionally.
- For this certain strategies that can be used is to have **suction accumulator** that when the load increases protects the compressor from liquid flooding.
- Therefore condenser can be designed to hold some liquid refrigerant if load variation is encountered.
- Other strategies include

1) VFD’S
2) Evaporator compartmentalisation for example through shading or fan speed control.

Controls….

- The heat pump should contain fail safe to protect the compressor and the system.
- Important parameters to monitor include.

1) Oil sump temperature
2) Compressor load conditions including pressure
3) Compressor overall current consumption

- Super heating of the refrigerant has to be controlled precisely so as to control the discharge temperature of the compressor.
- Discharge heat and compressor motor cooling can be controlled through external oil/ motor coolers. Compressors with this ability can be selected or if necessary a Natural convection or forced convection based controls can be introduced

Controls….

Discharge Temp Controls….

- Control of stepper motor expansion valve through DSH (Discharge Superheat) has shown desirable results.
- 30-45 degrees superheat has been identified as optimal for variety of refrigerants.
- This has shown to have a positive effect of 25% in A2W system. (Wasan, Supot, Paisarn 2012)
- Temperature sensitive tube for operating an expansion valve in a discharge side pipe line of a compressor has shown good results.

Summary….

- Heat Pump Operational Constraints firstly require effective refrigerant selection.
- Design Point is identification is important
- Thereafter, the compressor load can be managed.
- For this it will be a recipe of things however it is clear, low superheat is desired.
- For load variation there should always be ‘Failsafes’ in place and suction accumulator, electronic expansion valve are worth their **weight in Gold**