Chapter – 14 Refrigerants and Refrigerant Selection

Copy Right By:
Thomas T.S. Wan
温到祥 著
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Refrigerants for Industrial Refrigeration

What constitutes a good refrigerant? The desirable features of a refrigerant are as the following:

-- Non-Corrosive.
-- Acceptable vapor pressure characteristics.
-- Favorable flow rates of Lbs/Min and CFM.
-- Favorable Refrigerant Effect.
-- Non-Toxicity.
-- Non-Flammability.
-- Good Film Conductivity of Heat Transfer.
-- Good Thermal Stability.
-- Free Emission and Meets EPA (Environment Protection Agency) Regulations.
-- No O-Zone Problem.
-- No GWP (Global Warming Potential) Problem.
-- Low Cost for the Refrigerant & Relatively Low Cost for the Equipment Used.

There are about 115 refrigerant listed in ASHRAE Standard 34, none of the refrigerants fulfills all the desirable criteria of a good refrigerant. Therefore, the refrigerant selection is a matter of balancing between advantages and disadvantages for the particular installation.

The ASHRAE Standard 34 also defines the classifications of safety for the refrigerants:

Table 14.1 Refrigerant Safety Classification

Refrigerant Safety Classification		
Toxicity	Group A	Lower Toxicity
	Group B	Higher Toxicity
Flammability	Class 1	No Flame Propagation
	Class 2	Lower Flammability
	Class 3	Higher Flammability

If the Refrigerant is classified under group A1; that means the refrigerant is a lower toxicity with no flame propagation.

R-718 (Water) is nearly a good refrigerant; unfortunately, it cannot be used for any low temperature application, it is mainly used for absorption system for water chilling duty. Furthermore, the absorption system is more expensive than rotating equipment system using other type of refrigerant for the same temperature level application. The disadvantage of water use as refrigerant out weights the advantage, therefore, the R-718 (water) is not considered as a good refrigerant.

R-11, R-12, R-114 and R-13 are classified under safety group of A1, but are being phased out because of O-Zone and GWP problems.

R-123 was supposedly the replacement for R-11. Unfortunately, it is under B1 safety classification because the toxicity is high; the Allowable Exposure Limit (AEL) and Threshold Limit Value (TLV) is 10 PPM. R-123 refrigerant is basically used for centrifugal system because the volume flow is high and it is mostly used for water chilling duty.

At the present time, the common refrigerants used for industrial refrigeration are as the following:

Table 14.2 Common Refrigerants

Refrigerant	**Boiling Point @ Atm Pres.**	**Refrigeration System**	**Safety Classification**
R-134a, CH_2FCF_3	-15.0°F	High stage or Compound	A1
R-717 (Ammonia), NH_3	-28.0°F	High stage or Compound	B2
R-22 ,$CHClF_2$	-41.4°F	High stage or Compound	A1
R-290 (Propane), C_3H_8	-43.7°F	High stage or Compound	A3
R-1270 (Propylene), C_3H_6	-53.9°F	High stage or Compound	A3
R-170 (Ethane), C_2H_6	-127.9°F	Cascade low stage	A3
R-23, CHF_3	-115.7°F	Cascade low stage	A1
R-1150 (Ethylene), C_2H_4	-154.7°F	Cascade low stage	A3
R-50 (Methane), CH_4	-258.7°F	Cascade low stage	A3

The R-134a is the replacement for R-12. Therefore, the boiling point, the working pressure and the flow CFM for R-134a are very similar to R-12.

The safety classification of both R-134a and R-22 are A1. The GWP value for R-22 is 0.35 as compared to 0.26 for R-134a. The DWP for air cooled application might be lower if R-134a refrigerant is used instead of R-22; however, the capacity of a compressor rated on R-134a is about 30% to 40% less than R-22 for the same operating conditions.

R-717, ammonia is a very popular refrigerant because this refrigerant provides all the desirable features except the toxicity and the flammability ratings. The safety classification for ammonia is B2. The explosion range for ammonia is 16% to 25% mixed with air; the ignition source temperature is 1,203°F or higher.

The flammability class is “2” for ammonia, the electrical equipment using R-717 as refrigerant should be designed and constructed in accordance with hazardous location application if it is strictly in confirmation with the code requirements. However, many users in food processing industries waive this requirement; might be because of the narrow explosion range of ammonia and air mix and high ignition temperature.

Both R-290 (Propane) and R-1270 (Propylene) refrigerants are widely used for refrigeration systems, particularly for oil, petrochemical, hydrocarbon processing and chemical industries, it is because the electrical equipment used for those industries is required to confirm with hazardous regulations regardless what refrigerant is used.

Both R-290 and R-1270 do not have EPA, O-Zone or GWP problems; furthermore, it is a low cost refrigerant and it is convenient for those industries to handle this type of refrigerants. The character comparison between R-290 and R-1270 is very similar to the comparison between R-134a and R-22; a compressor rated on R-290 refrigerant will produce smaller capacity as compared to R-1270 for the same duty.

The above capacity comparisons are based on screw compressors. The centrifugal compressor is a high volume flow machine; therefore, it might be justifiable to select R-134a over R-22 or R-290 over R-1270 if a centrifugal compressor is used. However, it might be not be feasible to use R-717 refrigerant for centrifugal compressor, unless the refrigeration capacity is very large.

The costs for R-1270, R-290 and R-717 are the cheapest amount all the commonly used refrigerants.

R-170 (Ethane), R-23, R-1150 (Ethylene) and R-50 (Methane) are the refrigerant commonly used for the low stage of a cascade refrigeration system. R-23 is one of the group A1 refrigerants and it is used for non-hazardous installation. R-50 (Methane), R-170 (Ethane) and R-1150 (Ethylene) are group A3 refrigerants; therefore, all the electrical items including motors for the refrigeration system are to be designed and constructed in accordance with regulations of the NEC code for hazardous application.

Dual Refrigerants System of R22 and Ammonia (R717):

The comparisons between R-22 and R-717 are generally outlined as the following:

1.0 Heat transfer and thermodynamic properties of R-717 are better than R-22. Piping and valve sizes of R-717 system are smaller than R-22.

2.0 R-717 is one of the refrigerants under safety group B2; R-22 is A1 safety refrigerant. Electrical equipment for R-717 system is more expensive than R-22 if code requirement is not waived by the user.

3.0 R-22 has higher TR than R-717 based on same screw compressor size and same operating conditions.

4.0 R-717 has slightly advantage on BHP/TR at lower compression ratio as compared to R-22 for screw compressor; R-22 has better BHP/TR over R-717 at higher compression ratio.

5.0 The environmental effects of the R-22 refrigerant are:

Atmospheric Lifetime:	18 years
Ozone Depletion Potential (ODP):	5%
Global Warming Potential (GWP):	40%.
Availability of R-22 in the future:	Restricted

6.0 On the other hand, the environmental effects of R-717 are very favorable:

Atmospheric Lifetime:	<2 weeks
Ozone Depletion Potential (ODP):	0%
Global Warming Potential (GWP):	0%.
Availability of R-717 in the future:	No Restriction

The economical impact between R-22 and R-717 is hinged on the code requirement for the electrical items. If the electrical system for ammonia is to be designed and constructed in accordance with the NEC code requirement, then, the R-717 system might be more expansive than the R-22 system. However, if the user waives the NEC code compliance such as in food processing industries and is willingly to accept the toxicity classification of ammonia, then the ammonia might be better over R-22. However, the conclusion is not absolute; it is recommended that the analysis should be based on initial investment and annual energy consumption of the system.

Some of the application, the user prefers to use A1 group refrigerant such as R-22 for the installation. However, by knowing the availability of R-22 may be in jeopardy in the future, a provision is made that the refrigeration system is to be designed for the dual use of R-22 and R-717. That means the system is designed for the use of R-22 for now; in case the availability of the R-22 refrigerant is restricted in the future, the refrigeration system is to be converted to R-717 at that time.

The refrigerant flows and the general data for system using R-22 and R-717 are listed in Table 14.3. This comparisons are based on same size of screw compressor and under the same evaporative temperature of 10°F and same condensing temperature of 104°F.

Table 14.3 Comparisons R-717 and R-22

Description	Ammonia (R-717)	R-22
Same size compressor, ET/CT	ET=10°F CT=104°F	ET=10°F CT=104°F
Net Refrigeration Effect (NRE)	455.46 Btu/Lb	64.91 Btu/Lb
Capacity	209.3 TR	205.2 TR
Power consumption	363.5 BHP	364.2 BHP
BHP/TR	1.7367	1.7744
Evaporative pressure	38.5 Psia	47.5 Psia
Condensing pressure	225.6 Psia	222.4 Psia
Discharge temperature	197.5°F	168.0°F
Compressor Vi required	3.6	3.6
Refrigerant flow	92.0 Lbs/Min	632.3 Lbs/Min
Suction Specific Volume	7.832 Ft^3/Lb	1.206 Ft^3/Lb
Suction volume flow	720.5 ACFM	762.6 ACFM
Oil cooler heat rejection	488,200 Btu/Hr	206,200 Btu/Hr
Condenser heat rejection	2,978,000 Btu/Hr	3,235,000 Btu/Hr

The general guide lines and the major considerations for the refrigeration system design for the dual refrigerants of R-22 and R-717 application are as the following:

Compressor:

R-22 has higher volume flow than R-717.
R-22 has higher power consumption than R-717.
R-717 has higher discharge pressure than R-22.
R-717 has higher condensing pressure than R-22.
R-717 has higher adiabatic efficiency than R-22.
The compressor is to be based on R-22. But, all the parts are to be for R-717.

Condenser and Cooler:

Cooler heat transfer: R-717 has about 17% higher U-value than R-22.
Condenser heat transfer: R-717 has about 7% higher U-value than R-22.
The surfaces are to be based on R-22. But, materials are to be good for R-717.

Valves and Piping:

Valve sizes for Ammonia are smaller than R-22.
Piping sizes for Ammonia are smaller than R-22.
All the piping and valves are to be selected for R-22.
All the piping and valves materials are to be good for R-717.
Automatic control valves are to be for R-22; but, are changeable for R-717 in future.

Materials:

All materials are to be non-ferrous.
Carbon steel tubes are to be used for all heat exchanger.
No brass materials are to be in the system.
All the materials are to be good for both R-717 and R-22

Electrical Requirements and Considerations:

All the electrical are to be designed and constructed in accordance with R-717 requirement. All the electrical items, motors and control panel are to be designed and constructed for Class I, Division II in accordance with the NEC Code.

System Conversion:

The system is to be designed and selected for R-22 for initial operation. A complete kit is to be provided by the manufacturer for future conversion to R-717. Also, the system manufacturer shall submit a list of conversion procedure and instruction such as drain, purge, evacuation and part changes for the R-717 conversion.

Highlights of Safety and Code Required Procedures for the Installation:

If the system is to be fully complied with the code requirements, all the electrical items, motors and control panel are to be designed and constructed in accordance with the NEC code for Class 1, Division 2 hazardous location. The engine room ventilation rate is to be in accordance with the requirement of NFPA. ASHRAE 90.1 Standard also requires that no ammonia machinery or piping be located in the public hallway or public assembly areas.

Some users in food processing industries would accept the IIAR (International Institute of Ammonia Refrigeration) Ammonia Machinery Room Ventilation regulation as the substitute for NEC code. That means to use ventilation method to reduce the machine room to a non-hazardous location.

Pure Hydrocarbon and Mixed Hydrocarbons as Refrigerant

All the refrigerants R-50, R-170, R-290, R-600, R-1150 and R-1270 are the hydrocarbons and it is actually one of the components of the natural gas. The natural gas consists of the hydrocarbons of methane, ethane, propane, propylene, butane, pentane and etc. The specific gravity of the natural gas might vary from 0.6 to 1.3.

R-50 (Methane CH_4), R-1150 (Ethylene C_2H_4) and R-170 (Ethane C_2H_6) are used as the refrigerant for the low stage in a cascade refrigeration system. The refrigerants R-1270 (Propylene C_3H_6) and R-290 (Propane C_3H_8) are used as the refrigerant for the high stage. The R-600 (Butane C_4H_{10}) is mostly used as the refrigerant for heat pump application or used for water chilling duty.

Figure 14-1 shows the P-H diagram for R-22, the bubble point temperature and the dew point temperature are the same under the same pressure. Figure 14-2 is the P-H diagram for 100% pure Propylene (R-1270) and the Figure 14-3 is the P-H diagram for 100% pure Propane (R-290); it also shows the saturation temperatures are constant at constant pressure. However, if the hydrocarbon refrigerant is not pure and it is a mixture with other hydrocarbon, the P-H diagram for the mixture is shown in Figure 14-4, the saturated bubble point and dew point temperatures are not the same at the same pressure, or the saturated temperature changes in accordance with the equilibrium condition even under the same pressure.

Figure 14-5 is the P-H diagram for a Mole percent mixture of 95.39% of Propane, 3.26% of Ethane and 1.32% of Butane and other components of hydrocarbons. The Propane is not a pure substance, the bubble point and dew point temperatures are not the same even it is under saturated condition under same pressure. In this case, at a constant pressure of 14.9 Psia, the bubble point is -50°F and the dew point is -39°F.

Figure 14-6 is the P-H diagram for a Mole percent mixture of 80.7% of Propane, 19.2% of Ethane and 0.1% of Butane. The split between the bubble point temperature and the dew point temperature are much greater. For comparison, the saturated temperature would be -42.17°F at 14.9 Psia if it is a pure 100% Propane.

From the above cases, if the hydrocarbon such as R-1270, R-290, R-600 and etc. is to be used as the refrigerant, the purity of the refrigerant is to be in accordance with the ASHRAE Standard 34. Otherwise, the heat exchanger selection shall follow the equilibrium calculation if the refrigerant is a hydrocarbons mixture.

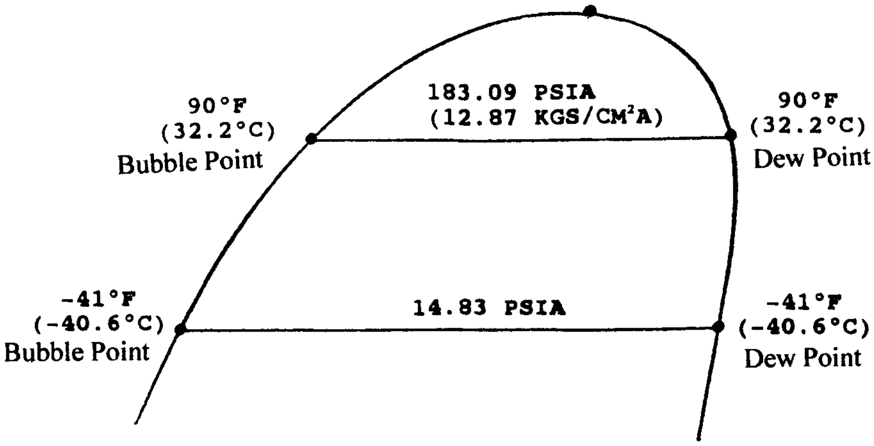


Figure 14-1 P-H Diagram R-22

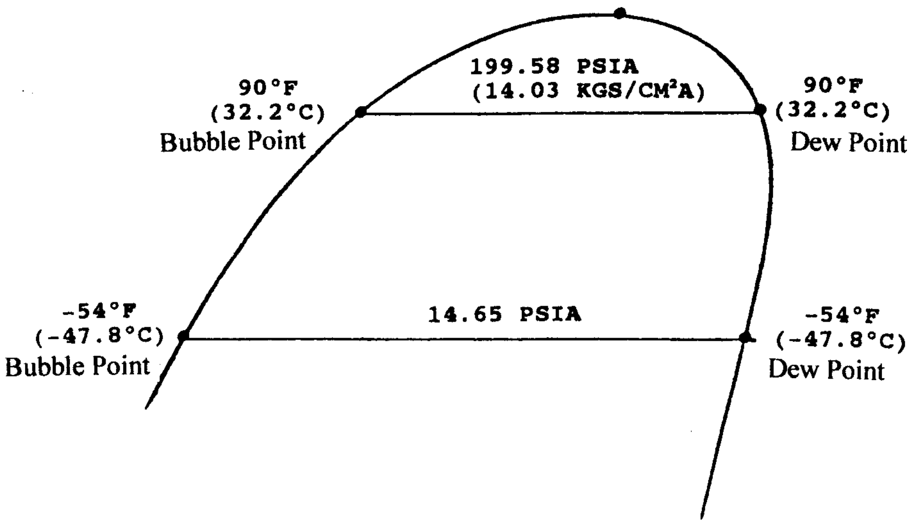


Figure 14-2 P-H Diagram, Pure Propylene (R-1270)

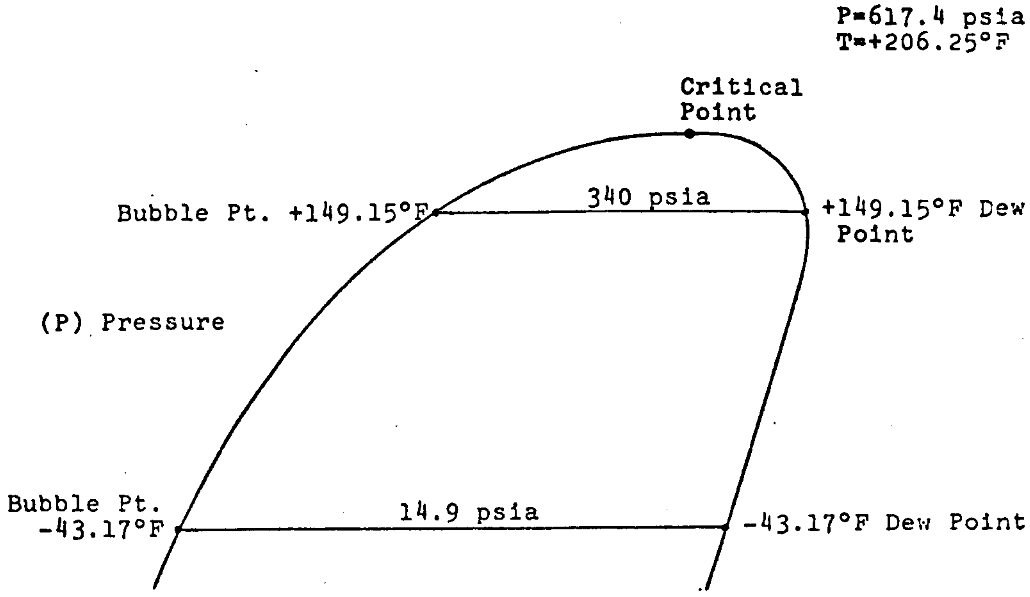


Figure 14-3 P-H Diagram, Pure Propane (R290)

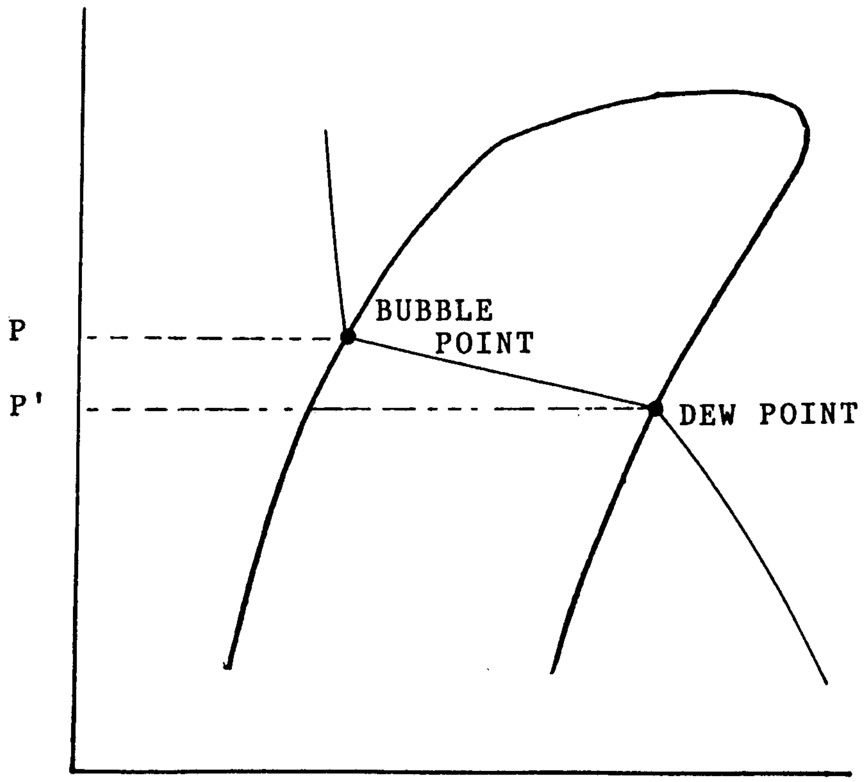
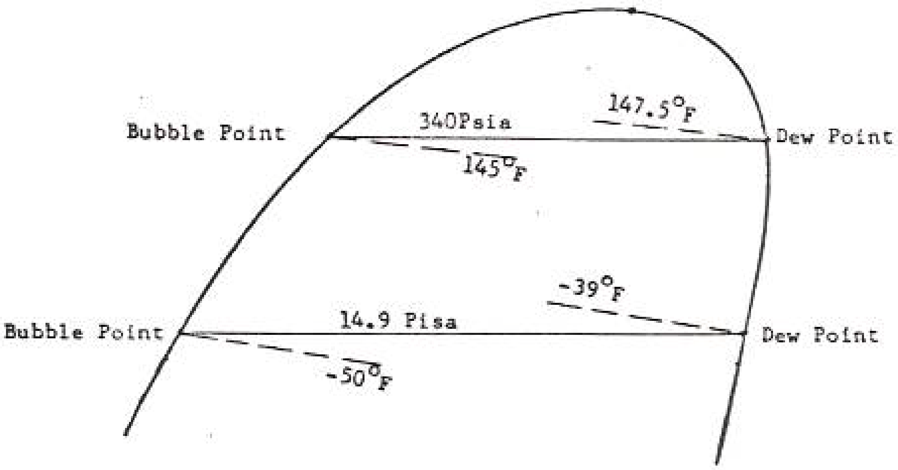
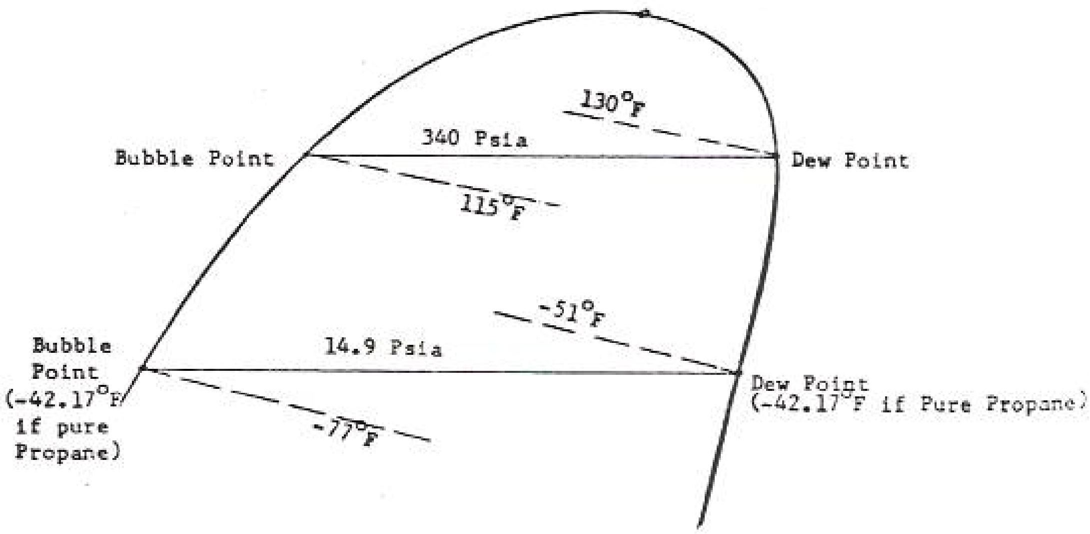


Figure 14-4 P-H Diagram, Mixed Hydrocarbons



Hydrocarbon mixture	
Propane	95.39% Mole
Ethane	3.26% Mole
Butane & other	1.35% Mole

Figure 14-5 P-H Diagram, Hydrocarbon Mixture



Hydrocarbon mixture	
Propane	80.7% Mole
Ethane	19.2% Mole
Butane	0.1% Mole

Figure 14-6 P-H Diagram, Mix Hydrocarbons