Future of Refrigerant

- A Manufacturer's Experience

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Topics

1. Refrigerant Candidates
2. Test results for Split Systems
3. Market Response
4. Conclusions

What we have....

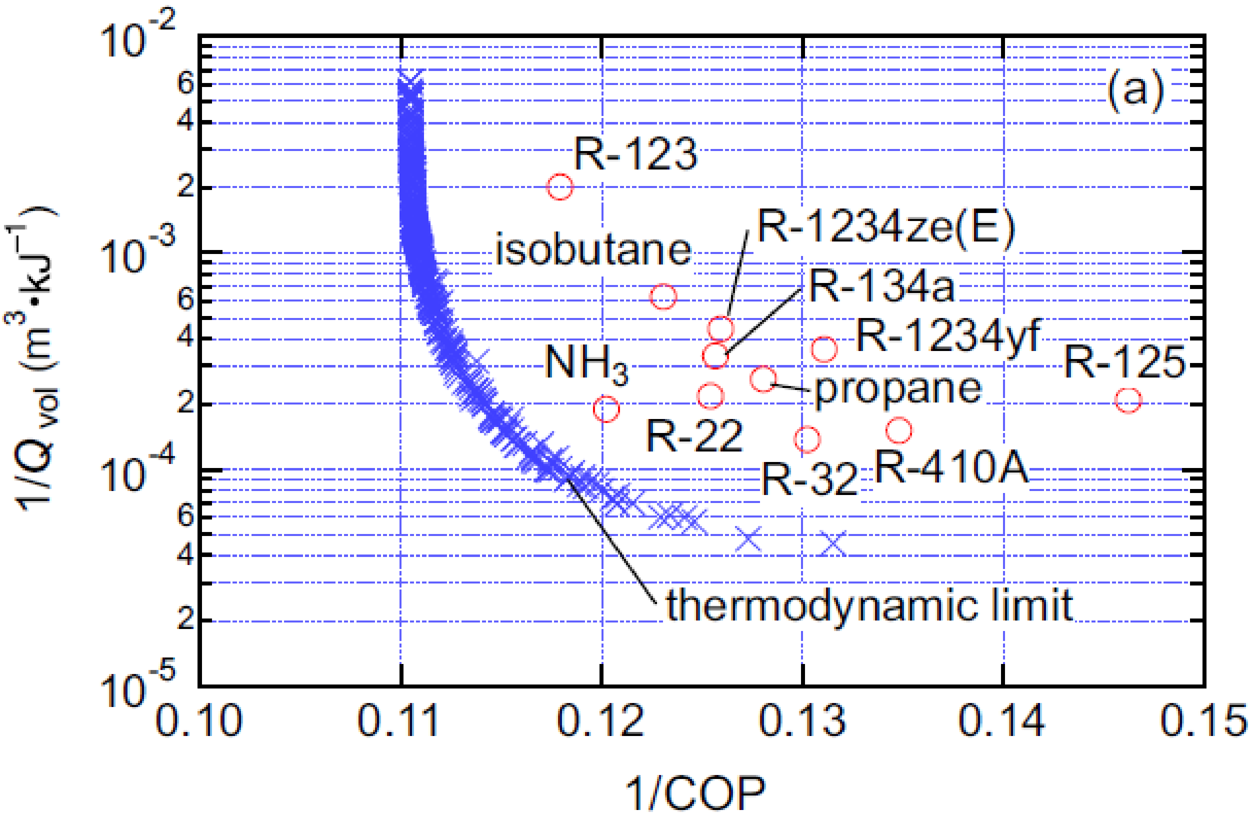
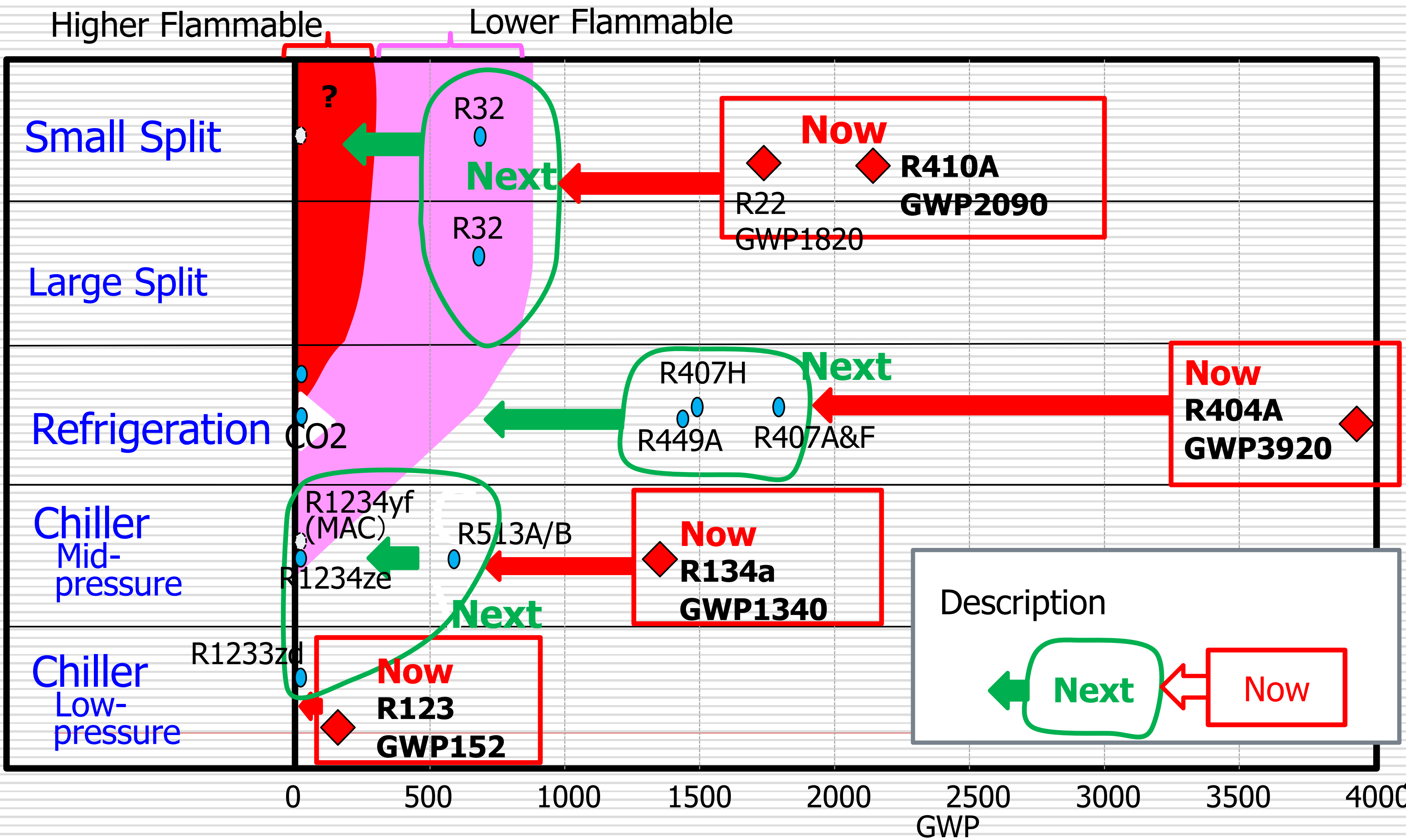


Fig. 1 – Pareto front (×) and selected current refrigerants (○) for the simple vapor compression cycle with temperatures representative of an air-conditioning application (T_{evap} = 10 °C, T_{cond} = 40 °C).

- Explored 56,000 small molecules
- Identified 1,200 candidates
- Screening criteria: GWP, flammability, stability, toxicity, and critical temperature.

M. McLinden, A. Kazakov, S. Brown, P. Domanski
4th IIR Conf. on Thermoph. Prop. and Transfer Processes of Refrigerants, Delft, The Netherlands, June 17-19, 2013

Refrigerants in Different Applications



Some Test Results

- Tested Refrigerants（Charge is optimized for EER)
  - R32
  - R410A
  - Blend A (R32/R1234yf)[70/30%]
  - R452B (R32/125/1234yf)[67/7/26%]
  - (R22)

- Tested unit
  - Nominal capacity 7.1 kW mini-split
  - Variable Speed “Swing(rotary)” Comp.
  - Electronic Expansion Valve
  - R32 dedicated design (Allow high & low flow rate)
- Test conditions
  - ISO 5151 T1(35℃) and T3(46℃) 3.5 kW- 7.5 kW range
- Test facility
  - ISO 5151 annex D “Air enthalpy method”

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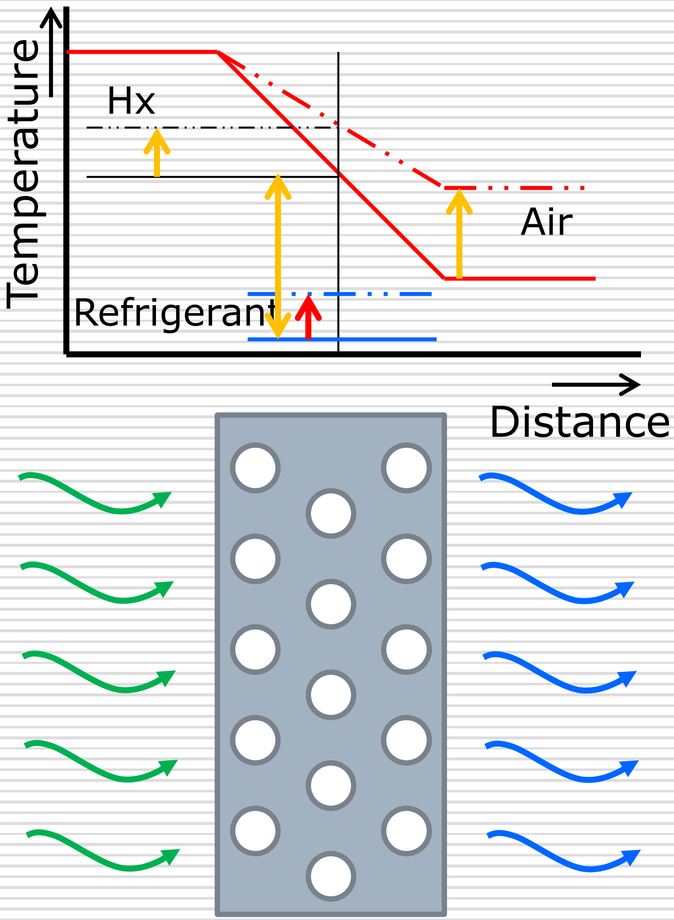
Thermo-Physical Properties(REFPROP 9.1)

			R32	R410A	Blend A	R452B	R22	(R290)
Typical Discharge Pressure *1		Mpa (psia)	3.14 (455)	3.07 (445)	2.71 (393)	2.65 (384)	1.94 (281)	1.71 (248)
Gas Density at typical Suction *1		kg/m^3 ($lbs./ft^3$)	29.2 (1.82)	40.3 (2.52)	29.3 (1.83)	29.9 (1.87)	28.0 (1.75)	13.4 (0.837)
Relative Thermo-physical Capacity*2	Cycle A*1	-	1	0.900	0.841	0.839	0.633	0.530
	Cycle B*3	-	1	0.862	0.833	0.832	0.638	0.522
Thermo-physical COP (EER)	Cycle A*1	kW/kW (Btu/kW)	5.52 [18.8]	5.32 [18.1]	5.53 [18.8]	5.55 [18.9]	5.84 [19.9]	5.76 [19.6]
	Cycle B*3	kW/kW (Btu/kW)	4.03 [13.7]	3.77 [12.8]	4.03 [13.7]	4.05 [13.8]	4.34 [14.8]	4.22 [14.3]

1. Condensing temperature at 50° C (122° F), evaporating temperature at 10° C (50° F), with 5 K (9° F) Sub cool, and with 5 ° C (9° F) Super heat. Zeotropes are evaluated to have the same mean temperature of the bubble point and the dew point.
2. At the same volumetric flow rate.
3. Condensing temperature at 60 ° C (140° F), evaporating temperature at 10 ° C (50° F), with 5 K (9° F) Sub cool, and with 5 K (9° F) Super heat

Basic issues with drop-in tests

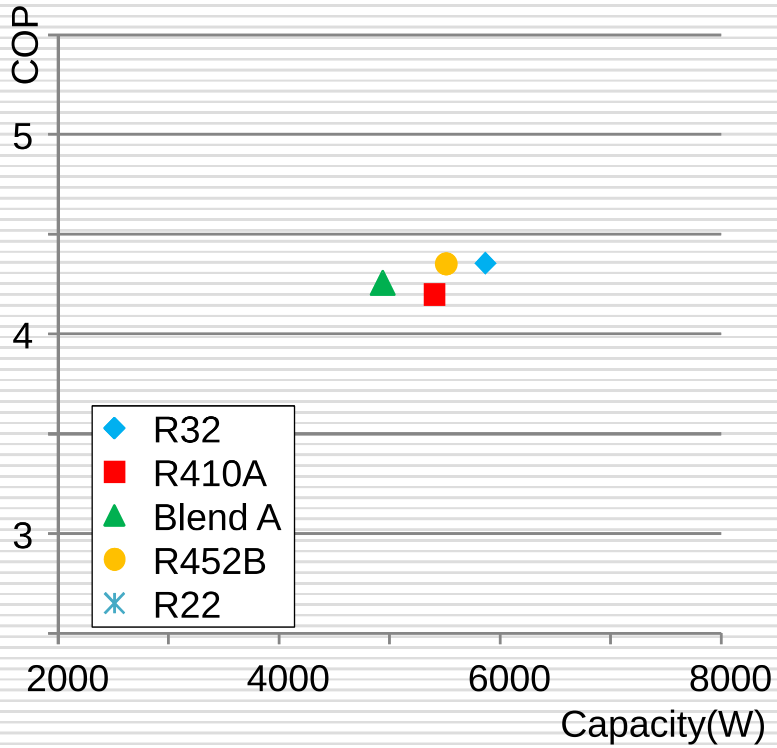


Air Heat exchanger

- If the capacity is not the same, the temperature of operation and COP will vary.
- Lower capacity refrigerants result in higher average air temperatures during cooling operation. Evaporating temperature of refrigerant and COP also increase.
- Taking such effect into account is essential for evaluation.

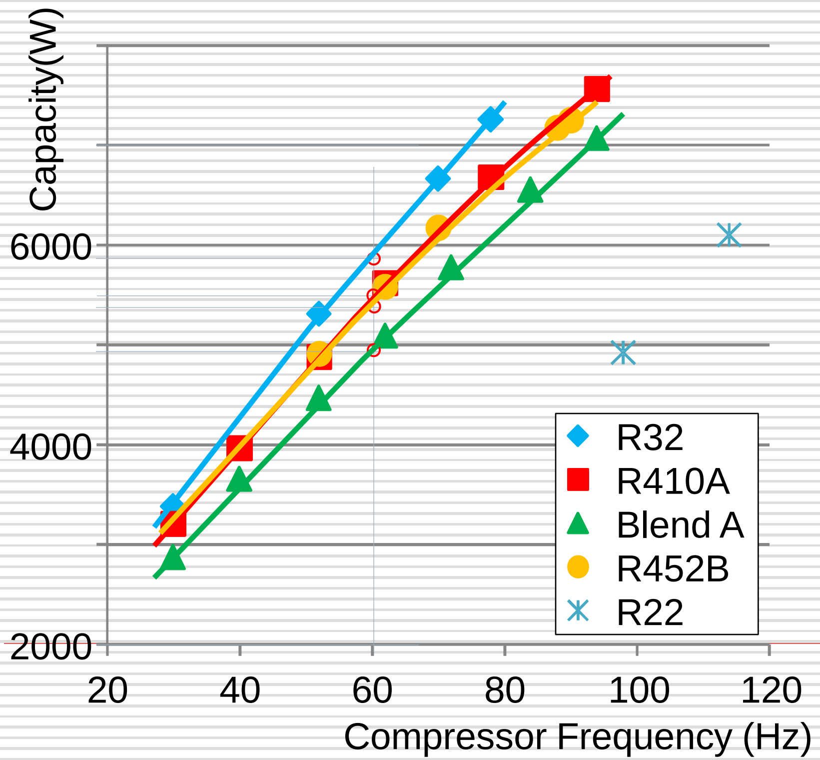
Drop-in test results at T1

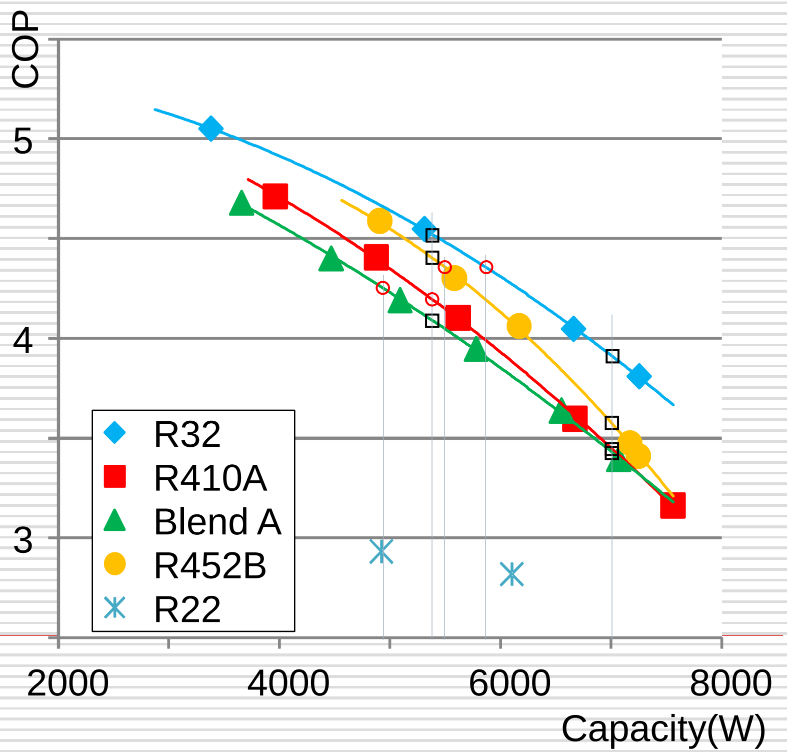
- Test results at 60 Hz, to mimic fixed speed compressor.
- Difficult to compare the results at different capacity.



Drop-in test results at T1

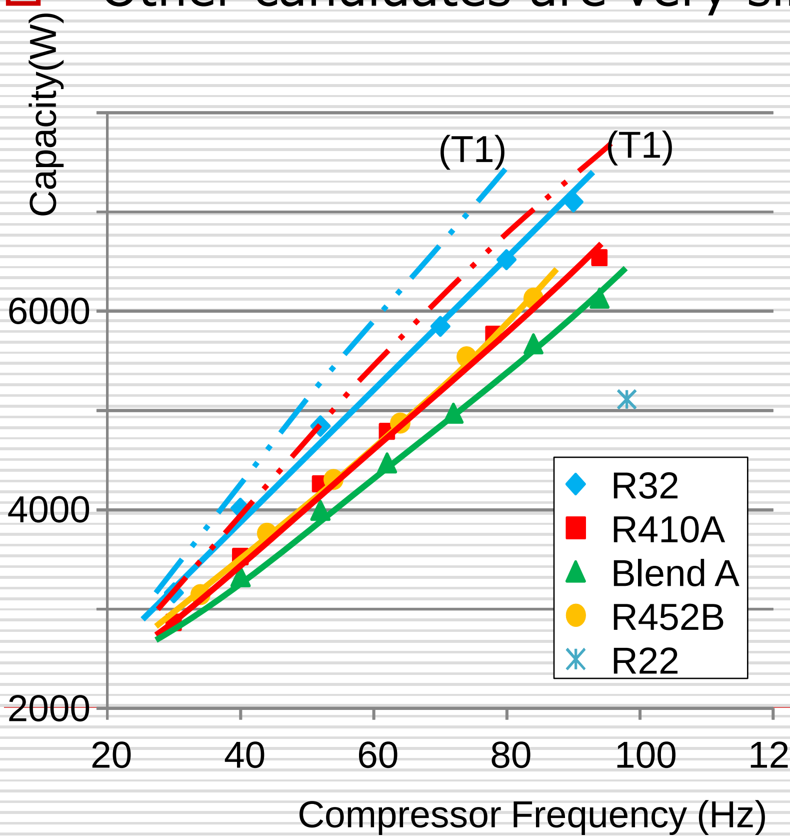
- R452B has similar capacity to R410A, but with better efficiency.
- R32 achieves the best efficiency at same capacity.
- Evaluation with Drop-in tests with fixed speed compressor is not easy. Lower capacity refrigerant appears with higher EER.

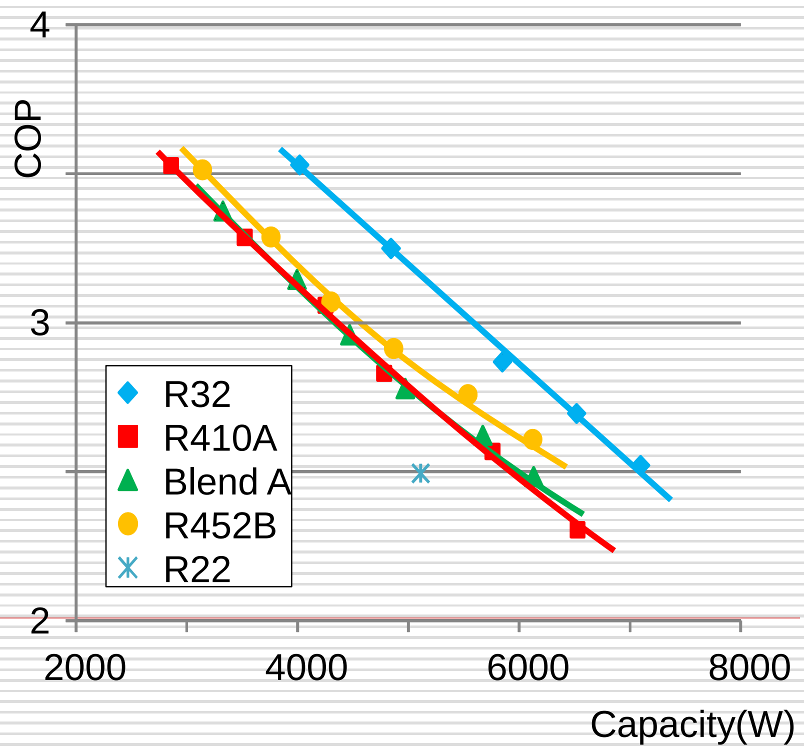




Drop-in test results at T3 (High amb)

- At a high ambient condition, the advantage of R32 is more significant due to the larger mass flow requirement and the higher operating temperature that is closer to critical temperature at T3.
- Other candidates are very similar to the R410A.





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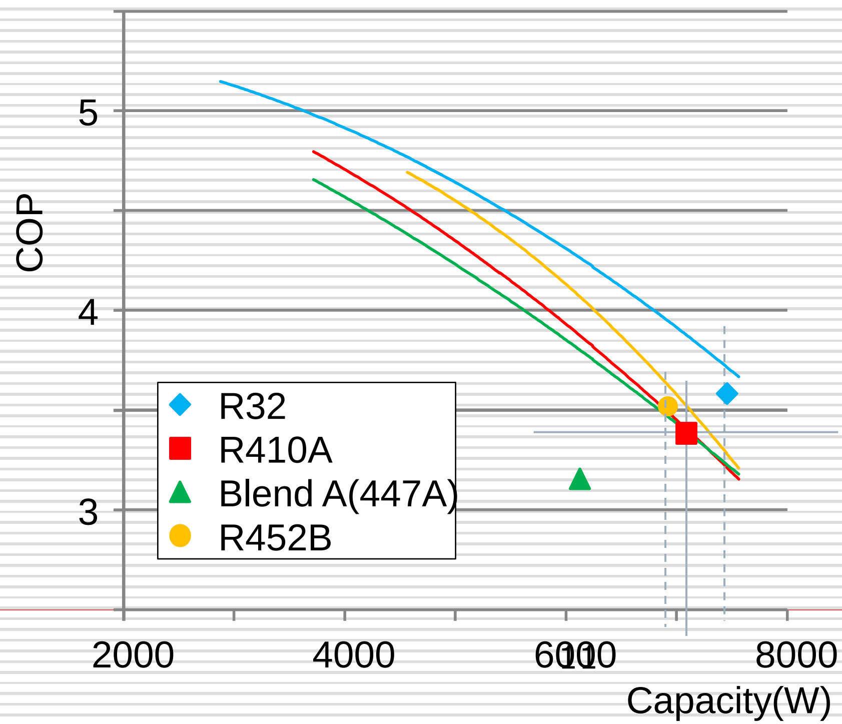
Comparison with ORNL Data

- Obtained data are compared with ORNL data reported to AREP II.
- EER with R32 and R452B in this study are better than ORNL data presumably due to high velocity HX design.
- Blend A and R447A data do not match though their composition resemble each other.



- **Curves indicate the results of this study.**
- **Plots are from ORNL data.**

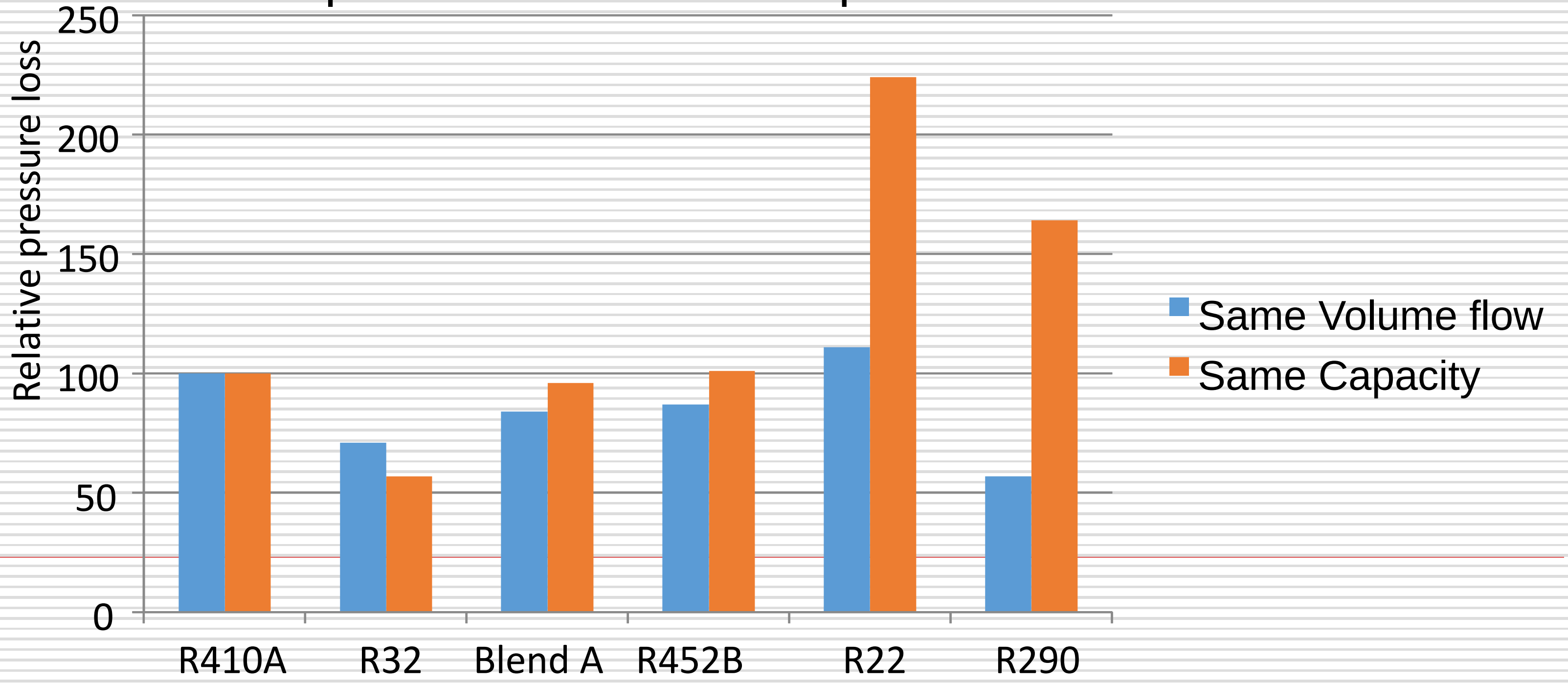
Comparison with simulation results

- Simulations with VapCyc® (Wincler et al., 2008) are also made to evaluate alternatives.
- The simulation results appear to be within a reasonable range from the measured data except for R452B.
- Thermo-physical property data of R452B needs to be reviewed.
- Performance of propane (R290) can be evaluated without safety issues.

	R410 A	R32	R447 A	Blend A	R22	R290	Remarks
Simulation	3.69 (12.5)	3.85 (13.1)	3.47 (11.8)	-	2.89 (9.83)	2.81 (9.55)	With 7 kW (23800Btu/h) capacity at T1 condition *Extrapolated value
Exp. data	3.45 (11.7)	3.92 (13.3)	-	3.43 (11.7)	2.76 (9.38) *	-	

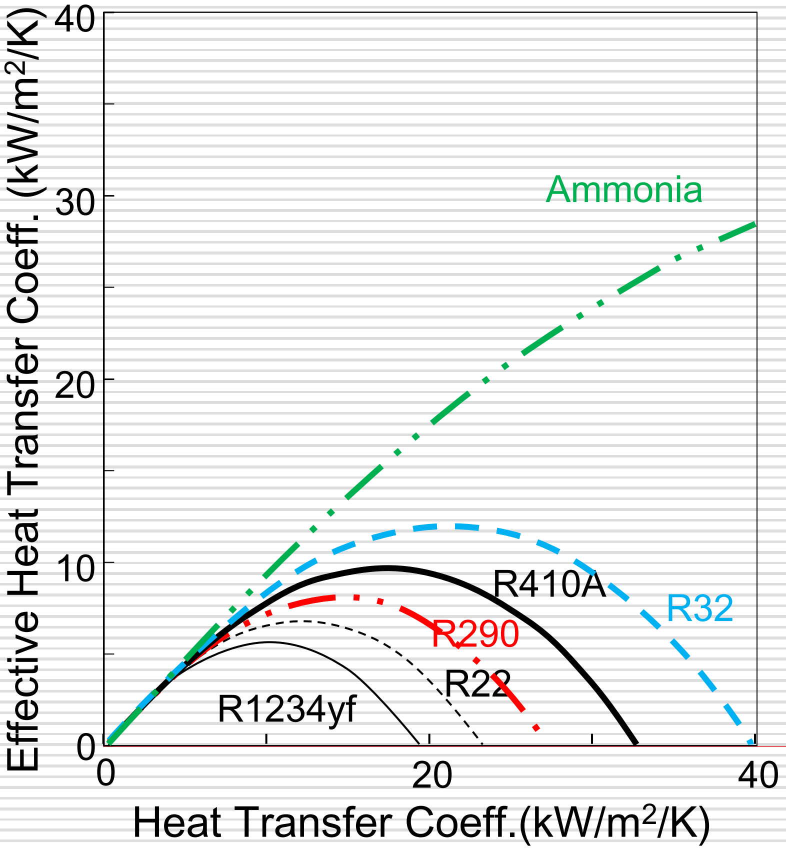
Relative Pressure Loss

- R22 and R290 have much larger pressure loss due to lower saturation pressure and larger volumetric flow.
- R410A and blends have similar pressure loss, but R32 can halve it after capacity adjustment.
- Pressure loss after capacity adjustment largely differs from that of Drop-in test with fixed speed unit.



Heat transfer with Pressure loss

- Generally, simple and light molecules with reasonable saturation pressure have advantage in heat transfer - pressure loss correlation.
- Zeotropes have a drawback in performance due to preferential phase change.



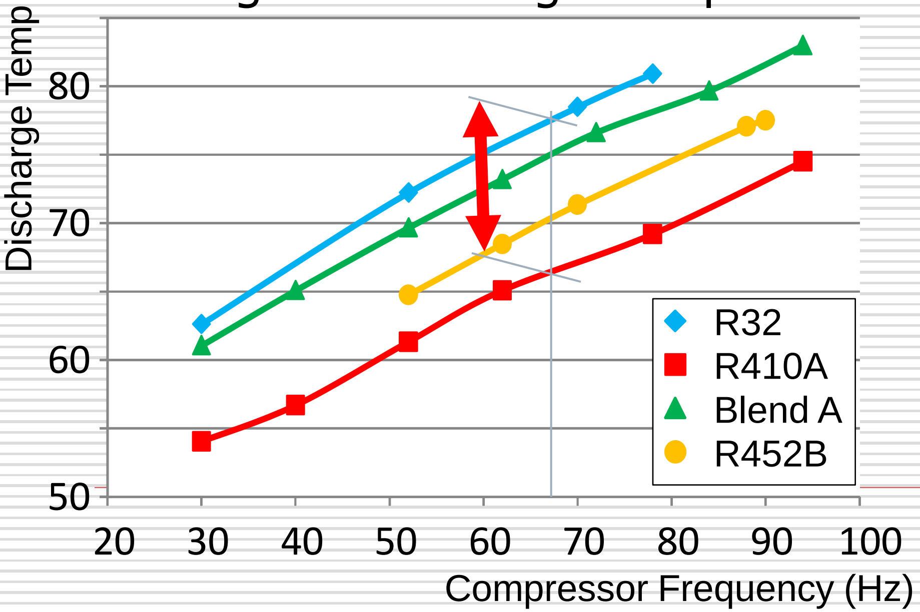
- Drop-in tests do not allow comparing performance with various refrigerants at the same loading to the heat exchanger or at the optimum mass flow rate.
- The advantage of R32 in heat transfer may not be observed with drop-in test to R410A unit. Mass flow rate may be too low for R32.
- Heat transfer of R290 is better than R22, but not so good as 410A and R32.

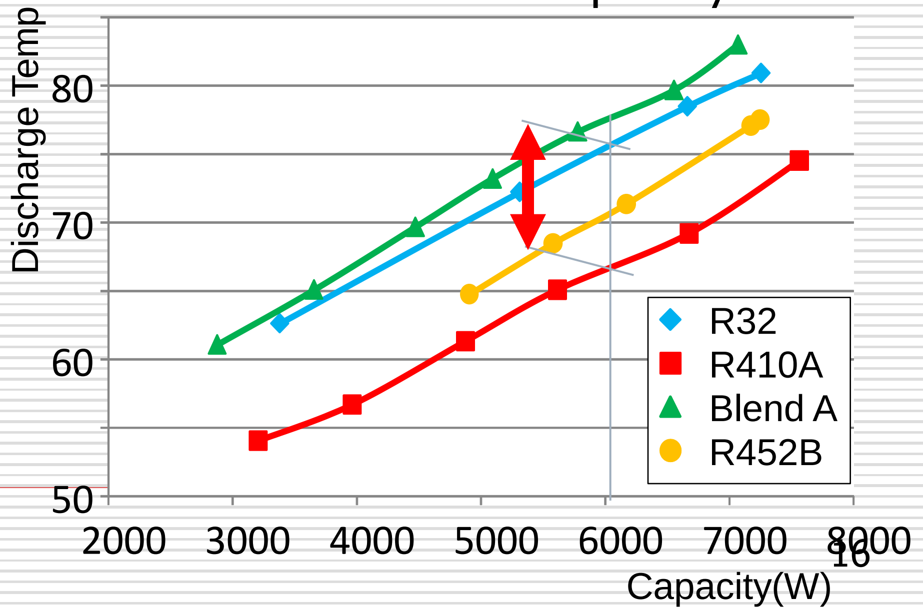
Lubricant Impact

- Miscibility of R32 to conventional POE is lower than R410A. Some lubricants may need to be modified for R32.
- Some data indicate significant reduction in compressor volumetric efficiency with R32, but not others.
- On the contrary, HCs are highly miscible with mineral oil. It results in insufficient viscosity. Compressors can run through performance tests, but fail in a few months or in a few years.
- Low viscosity due to dilution by HC refrigerant increases energy efficiency due to low pressure loss in suction pipe and mechanical loss. Such effect will disappear after lubricant optimization. But, it appears with drop-in tests.
- Proper evaluation of alternative refrigerants require lubricant optimization in some cases.

Discharge temperature

- Discharge temperature also needs to be evaluated at the same capacity condition.
- The high discharge temperature issue of R32 is somewhat exaggerated by its higher capacity. If it is evaluated at the same capacity condition, the difference against R410A is reduced.
- The high glide blend may have higher discharge temperature than R32 due to the higher suction temperature for glide. Blend A has higher discharge temperature than R32 at the same capacity.





Refrigerant charge and Global Warming Impact

- Optimum charge amount and capacity differ depending on the refrigerant. The charges for each refrigerant were optimized for EER in this study.
- Global warming impact evaluation of refrigerants should be made with the same unit (amount of material) at the same capacity and EER.
- The charge amount difference as well as the capacity and EER difference should be taken into account.
- Blends and R32 can reduce warming impact of R410A by 70-80%.
- Assumption of ASHRAE 34 (85% gas and 15% liquid fill in appliance) appears to work in many cases.

	R410A	R32	Blend A	R452B	R22
GWP	2088(1)	675(0.32)	473(0.23)	698(0.33)	1810(0.87)
Actual (optimized) Charge amount[g (lbs.)]	1880 (4.14)	1550 (3.42)	1700 (3.75)	1650 (3.64)	2340 (5.18)
Estimated charge amount [g]*	1890	1550	1550	1690	1740
Capacity correction	0	-13.9%	+0.3%	-3.4%	0
Actual Impact Ratio	1	0.23	0.21	0.28	1.07

* Calculated charge amount for each refrigerant using the ASHRAE 34 appliance charge assumption of 85% gas and 15% liquid at condenser.

Summary of Test Results

- Refrigerant evaluation with an appliance should be made at the same capacity (at the same loading on HX) with variable speed compressor.
- Adding a lower pressure fluid or higher molar mass fluid to R32 reduces the energy efficiency.
- Large temperature glide and low volumetric capacity make it even worse.
- The high discharge temperature issue of R32 is mitigated after compressor capacity optimization.
- The climate impact of refrigerants should be evaluated taking required charge amount and achievable capacity into account. Simple GWP value may not properly show actual impact.

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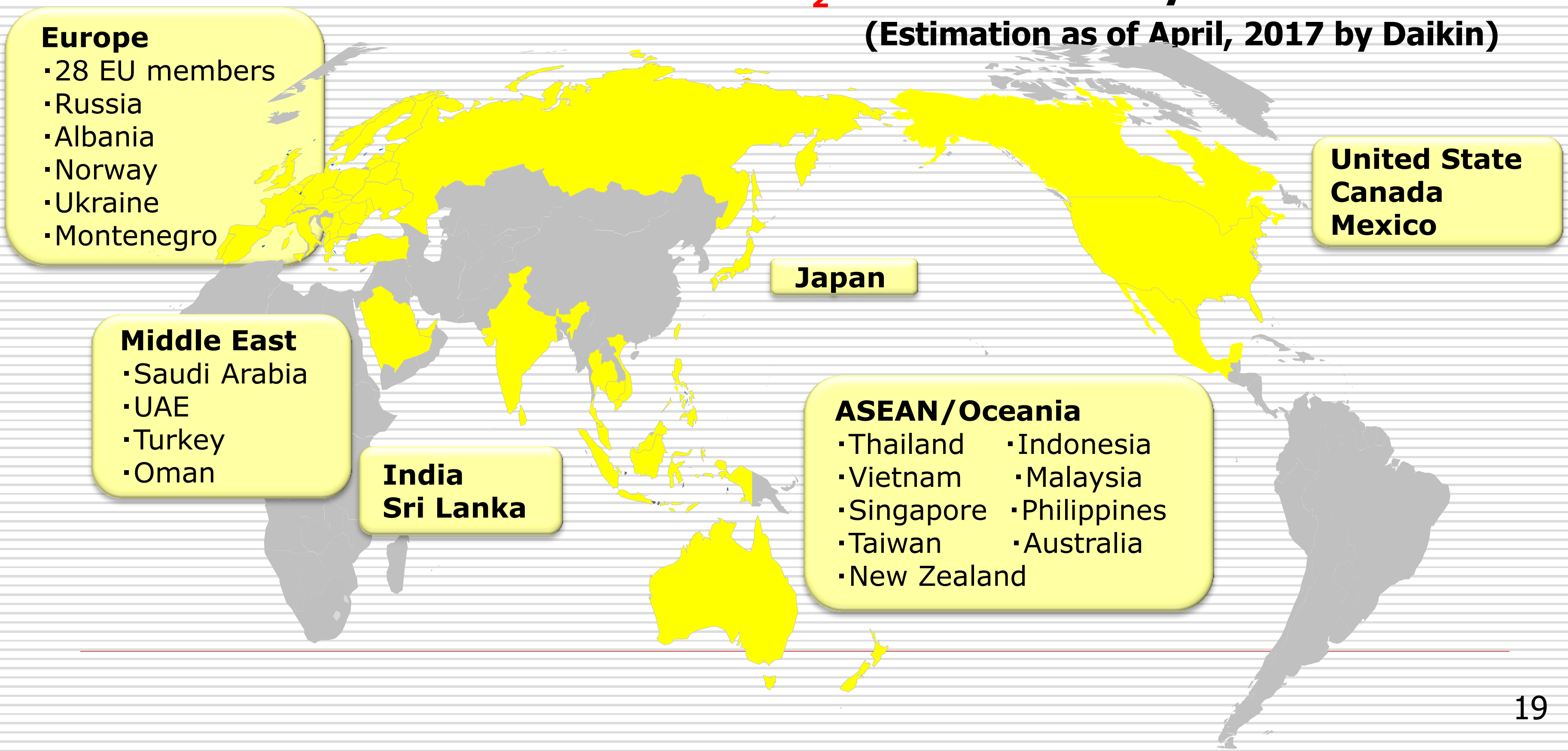
As a Consequence

- About **27 million** R32 RAC units have been shipped worldwide
- Daikin alone has shipped about 10 **million units** in **50 countries**
- More than **47 million tons of CO_2** were reduced by R32

(Estimation as of April, 2017 by Daikin)



Conclusions

1. **We have a very limited choice**
2. **R32 shows remarkable results for Split Systems**
3. **Market response is very positive**
4. **Safety regulations need to be updated in some regions**