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Refrigerant R290, or propane, is a possible replacement for other refrigerants, which have high impact on environment, in small hermetic systems, like factory made commercial refrigerators and freezers. It has zero ozone depletion potential ODP and a neglectible global warming potential GWP. Furthermore it is a substance which is a part of petrol gases from natural sources.

The refrigerant R290 has been in use in refrigeration plants in the past, and is still used in some industrial plants. In domestic heat pumps and air conditioners R290 has been used

in Germany for some years, however, with different level of success. Because of the availability of propane all over the world it has been discussed widely for CFC replacement.

Propane R290 is a possible refrigerant for this application, with good energy efficiency, but special care has to be taken to the flammability of propane.

1.0 Refrigerant

The properties of R290 differ from other refrigerants commonly used in small hermetic systems, as shown in table 1. This leads to a different design of details in many cases.

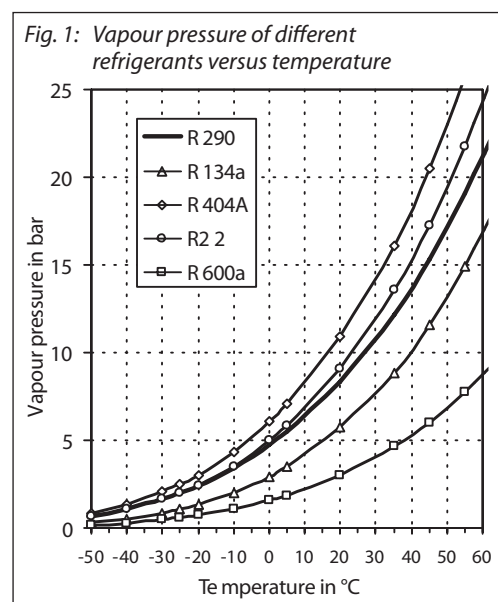
Table 1: Refrigerant data comparison

Refrigerant	R290	R134a	R404A	R22	R600a
Name	Propane	1,1,1,2-Tetra-flouro-ethane	Mixture R125 R143a R134a	Chloro-difluoro-methane	Isobutane
Formula	C ₃ H ₈	CF ₃ -CH ₂ F	44/ 52/4	CHF ₂ Cl	(CH ₃) ₃ CH
Critical temperature in °C	96.7	101	72.5	96.1	135
Molecular weight in kg/kmol	44.1	102	97.6	86.5	58.1
Normal boiling point in °C	-42.1	-26.5	-45.8	-40.8	-11.6
Pressure at -25 °C in bar (absolute)	2.03	1.07	2.50	2.01	0.58
Liquid density at -25 °C in kg/l	0.56	1.37	1.24	1.36	0.60
Vapour density at t ₀ -25/+32 °C in kg/m ³	3.6	4.4	10.0	7.0	1.3
Volumetric capacity at -25/55/32 °C in kJ/m ³	1164	658	1334	1244	373
Enthalpy of vaporisation at -25 °C in kJ/kg	406	216	186	223	376
Pressure at +20 °C in bar (absolute)	8.4	5.7	11.0	9.1	3.0

1.1 Pressure

A difference between R290 and R134a is found in the pressure level, which is closer to R22 and R404A, e.g. at -25 °C evaporation the pressure is roughly 190 % of R134a, 81 % of R404A, 350% of R600a or almost exactly that of R22. In connection with this the normal boiling point is close to R22 also. Evaporators will thus have to be designed similar as for R22 or R404A.

The pressure level and critical temperature are almost like R22. However, the discharge temperature is much lower. This gives the opportunity to work at higher pressure ratios, means lower evaporating temperatures, or at higher suction gas temperatures.



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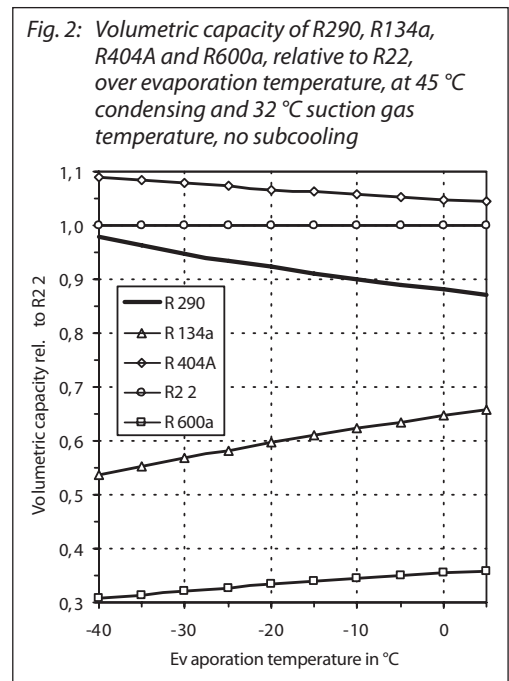
1.2
Capacity

R290 has roughly 90 % of R22 or 150 % of R134a volumetric capacity at 45 °C condensing temperature, as seen in fig. 2.

Because of this the necessary compressor swept volume is close to R22 also, and 10 % to 20 % larger than for R404A.

The volumetric capacity is approx. 2.5 to 3 times that of R600a. Thus the choice for either R290 or R600a will lead to differences in system design because of very different necessary volume flow for same refrigeration need.

The volumetric cooling capacity is a value calculated from suction gas density and enthalpy difference of evaporation.



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1.3
Refrigerant charge

If R290 would be charged into an unchanged refrigeration system, charge amount counted in grams would be much lower. However, calculated in cm³, the charge would be roughly the same liquid volume in the system. This gives charges of approx. 40 % of R22 or R404A charge

in grams, according to the data from table 1, which also corresponds with empirical values.

Maximum charge according to safety regulations is 150 g for household refrigerators and similar applications, which corresponds to approx. 360 g of R22 or R404A.

1.4
Purity

Refrigerant R290 specification is not found in international standards. Some data are enclosed in the German standard DIN 8960 of 1998, which is an extended version of ISO 916. The purity of the refrigerant has to be judged from chemical and stability side, for compressor and system lifetime, and from thermodynamic side regarding refrigeration system behaviour and controllability.

a little less narrow for specific refrigerants and impurities combinations after extensive evaluation.

For the time being no refrigerant quality according to an official standard is on the market. The specifications of possible qualities have to be checked with the supplier in details. Liquefied petrol gas LPG for fuel applications or technical grade 95 % purity is not sufficient for hermetic refrigeration. Water, sulfur and reactive compounds contents has to be on a lower level than guaranteed for those products. Technical grade 99.5 %, also called 2.5, is widely used.

The specification in DIN 8960 is a safe general hydrocarbons refrigerant specification, adopted from other refrigerants criteria catalogue and covering propane, isobutane, normal butane, and others. Some points can possibly be accepted

Table 2: Specification of R290 according to DIN 8960 - 1998

	Specification	Unit
Refrigerant content ¹⁾	≥ 99.5	% by mass
Organic impurities ²⁾	≤ 99.5	% by mass
1.3-Butadiene ³⁾	≤ 5	ppm by mass
Normal Heptane	≤ 50	ppm by mass
Benzene ⁴⁾	≤ 1	ppm per substance
Sulfur	≤ 2	ppm by mass
Temperature glide of evap.	≤ 0.5	K (at 5 to 97 % destill.)
Non condensable gasses	≤ 1.5	% vol. of vapour phase
Water ⁵⁾	≤ 25	ppm by mass
Acid content	≤ 0.02	mg KOH/g Neutralization
Evaporation residue	≤ 50	ppm by mass
Particles/solids	no	Visual check

- 1) This content is not explicitly stated in DIN 8960. Only the impurities are listed and limited. The main content is the rest up to 100 %.
- 2) From compressor point of view a butane content up to approx. 1 % is acceptable in the R290.
- 3) This is a maximum value for every single substance of the multiple unsaturated hydrocarbons.
- 4) This is a maximum value for every single aromatic compound.
- 5) This is a preliminary value, to be reviewed with growing experience.

**2.0
Materials**

Refrigerant R290 is used with polyolester oil in Danfoss compressors, so material compatibility is almost identical to R134a or R404A situation from oil side. R290 is chemically inactive in refrigeration circuits, so no specific problems should occur there. Solubility with ester oil is good. Direct material compatibility is less problematic. On some rubbers, plastics and

especially chlorinated plastics however, problems have been observed, but these materials are normally not present in small hermetic systems. Some materials, on which problems have been reported by different testers, are listed in the table 3. On critical materials test have to be performed for the specified use.

Table 3: Material compatibility

Material	compatible
Butylic rubber	no
Natural rubber	no
Polyethylene	depends on conditions
PP	no
PVC	no
PVDF	no
EPDM	no
CSM	no

**2.1
Driers**

For domestic refrigerators the common desiccant is a molecular sieve, a zeolithe. For R290 a material with 3 Å pores is recommended, like for R134a, e.g. UOP XH 7, XH 9 or XH 11, Grace 594, CECA Siliporite H3R. Pencil driers for R134a can possibly be used for R290, if they are tested according to IEC / EN 60 335 burst pressure demands.

If hardcore driers are to be used, please ask the manufacturer for compatibility to R290. Danfoss type DCL driers can be used.

**3.0
Flammability and safety**

The main disadvantage discussed in connection with R290 use is the risk based in its flammability. This leads to necessity for very careful handling and safety precautions.

Table 4: Flammability of propane

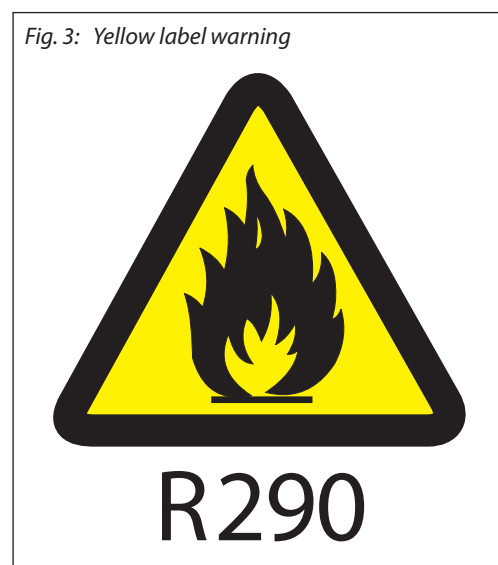
Lower explosion limit (LEL)	2.1%	approx. 39 g/m ³
Upper explosion limit (UEL)	9.5%	approx. 177 g/m ³
Minimum ignition temperature	470 °C	

Because of the flammability of propane in a wide concentration range safety precautions are necessary, on the appliance itself and in the manufacturing factory. The risk assessments behind these two situations are quite different. Main common starting point is, that accidents need to have two essential preconditions. One is the flammable mixture of gas and air and the other is the ignition source of a certain energy level or temperature.

These two have to be present together for combustions, so avoidance of this combination has to be proven.

Danfoss Compressors for R290 have in-ternal protectors and PTC starters or special relays, both preventing from sparks coming out near the compressor, because it can not be guaranteed

to hold surrounding air below LEL in case of leaks close to the compressor. They are equipped with a yellow label warning for flammable gas, like shown in fig. 3.

Fig. 3: Yellow label warning


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**3.1
Appliance**

For safety testing of household refrigerators and similar applications a standard has been established in Europe, IEC Technical Sheet TS 95006. It is also transferred to an amendment to IEC / EN 60 335-2-24, which is the normal electrical safety standard.

Approvals of refrigerators using hydrocarbons as refrigerant are done according to the procedures of the TS in Europe since 1994.

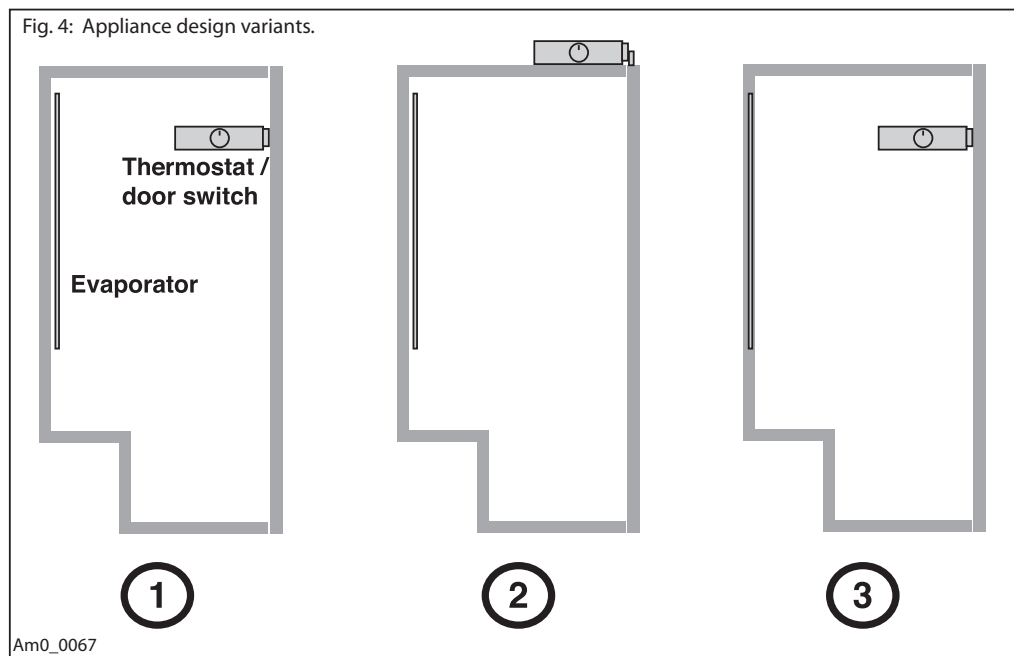
The methodology of TS and the amendments derived from this are base for the following short description.

Other applications have to take different national standards and legislation into account, e.g. EN 378, DIN 7003, BS 4344, SN 253 130, which can have different demands.

- All electrical elements switching during normal operation are taken to be possible ignition sources. This includes thermostat, door contacts for lighting, on/off and other switches, like superfrost, compressor relays, external klixon, defrost timers and so on.
- All refrigerant containing parts are taken to be possible refrigerant sources through leaks. This includes evaporators, condensers, door heaters, tubings and the compressor
- Maximum refrigerant charge is set to be 150 g. By keeping the charge to max. 25 % of lower explosion level LEL, which is approx. 8 g/m³, for a standard kitchen, ignition risk is very low, even if refrigerant distribution in case of leakage is uneven for some time first

The main target of the safety precautions is to separate rooms with refrigerant containing parts from rooms with switching elements.

Fig. 4: Appliance design variants.



In fig. 4 three principal possibilities are shown. Option 1 has evaporator and thermostat/door switch both located in the storage volume. This is critical for flammable refrigerants and should not be used. Option 2 has evaporator inside and thermostat/door switch outside, on top. This normally gives a safe solution. Option 3 has thermostat/door switch inside, but evaporator foamed in place behind the inner liner. This is a possible solution used in many cases. Chosen option has to be designed and proven in leakage test according to TS 95006 and IEC / EN 60335 demands.

On many refrigerator or freezer designs this separation is already the existing situation.

- Large free standing bottle coolers and freezers often have all electrical switches in the top panel.
- Some refrigerators have the evaporators hidden behind the liner, in the foam, means not in the cabinet space where thermostats and so on are allowed in this case.

Critical situation is given whenever it is not possible to avoid evaporator and thermostat or switches being in the cabinet. In this case two possibilities are left.

- Thermostats and switches have to be changed to sealed versions preventing gas from penetrating them and thus reaching the switching contacts. Danfoss offers electronic thermostats suitable for this application.
- Fans inside the refrigerated compartment have to be safe and sparkfree even if blocked.
- Electrical connectors and lamp holders have to be proven according to certain specifications.

**3.1
Appliance (continued)**

Every R290 appliance type has to be tested and approved according to the TS / IEC / EN procedures, by an independent institute, even if all above mentioned criteria are included in the design. Please see the standards for details.

Instructions for use should contain some informations and warnings for careful handling, like not to defrost freezer compartments with knives, and for installing in a room with at least 1 m³ of space per 8 g of charge, the latter to be seen on the type label.

Systems using relays or other electrical components near the compressor must meet the specifications. These are including

- Fans at the condenser or compressor must be sparkfree even when blocked or over loaded. Either they have to be designed not to need a thermal switch, or this switch has to meet IEC 60079-15.
- Relays have to meet IEC 60079-15 or being placed where a leakage can not produce a flammable mixture with air, e.g. in a sealed box or at high altitude. The starting accessory of Danfoss SC compressors is delivered with a long cable for placing in a separate electrical installation box.

The refrigerant containing system and the safety system design is to be approved and controlled regularly by local authorities normally. Below the design principles for installations in Germany are given. In many details this is based on regulations for liquified gas installations. Specialities are found around the charging stations, where gas connectors are to be handled frequently and a charging of the appliances occurs.

**3.2
Factory**

The basic principles for safety are

- Forced ventilation to avoid local accumulation of gas.
- Standard electrical equipment except for the ventilation fans and safety systems.
- Gas sensors continuously monitoring in possible leakage areas like around charging stations, with alarm and doubling of ventilation at 15 % to 20 % of LEL and with disconnection of all non explosion proof electrics in the monitored area at 30 % to 35 % of LEL, leaving the fans running at full speed.
- Leakage test on appliances before charging to avoid charging of leaking systems.
- Charging stations designed for flammable refrigerants and connected to the safety systems.

Safety system design can be supported by suppliers of charging stations and gas sensing equipment in many cases. For handling of R290 in small containers, the rules are less strict in some countries.

**4.0
Refrigeration system design**

In many cases of transition from non flammable refrigerants to R290 the appliance cabinet has to be modified for safety reasons as listed in section 3.1. But changes can additionally be necessary for other reasons.

Refrigerant containing system parts have according to IEC / EN 60335 to withstand a specified pressure without leaking. High pressure side has to withstand saturation overpressure of 70 °C times 3.5, low pressure side has to withstand saturation overpressure of 20 °C times 5. This gives the following for R290:

- 87 bar overpressure High Pressure side
- 36.8 bar overpressure Low Pressure side

National standards could have different specifications, depending on the application.

4.1
Heat exchangers

The refrigeration system efficiency will normally not cause a need for changing evaporator or condenser size, means outer surface can be left the same as with R22 or R404A.

Inside design of the evaporator possibly needs some modification, because the refrigerant volume flow is different, according to the compressor swept volume. To keep the refrigerant flow speed within the recommended range of 3 to 5 m/s it may be necessary to adopt the cross flow sections.

Rollbond evaporators can maybe not be used because of the high demands on burst pressure. Special care has to be taken when designing the accumulator in the system. When using R22 or R134a the refrigerant is heavier than the oil used, while with R290 the refrigerant is less heavy, as can be seen in the data table 1.

This can lead to oil accumulation if the accumulator is too large, especially too high, and has a flow path which does not guarantee emptying sufficiently during startup phase of the system.

4.2
Capillary

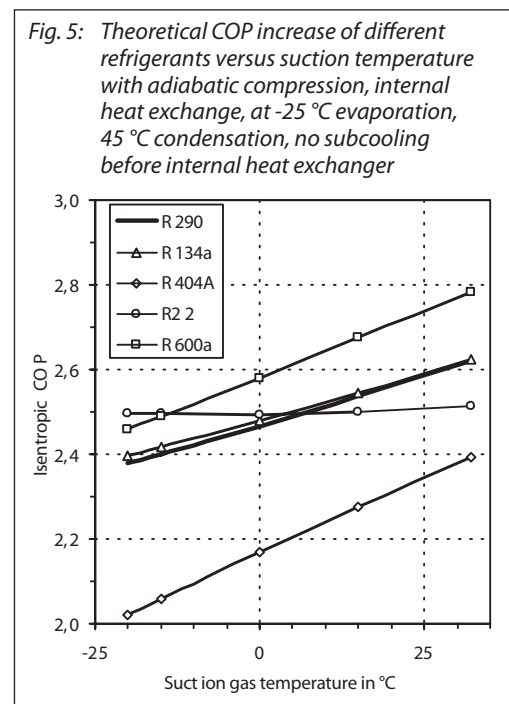
For R290 experience shows the need for a capillary flow rate almost similar to R404A. At least this is a good starting point for optimization.

As with R134a, R404A and R600a the suction line heat exchanger is very important for system energy efficiency of R290, which it was not for R22, see fig. 5. The figure shows increase of COP with superheat from few K up to +32 °C return gas temperature, where a range from +20 °C to approx. +32 °C is usual for small hermetic systems.

This large increase in COP for R290 is caused by a high vapour heat capacity. In combination with the need for keeping the refrigerant charge close to maximum possible in the system, thus giving no superheat at evaporator outlet, the suction line heat exchanger has to be very efficient for preventing air humidity condensation on the suction tube. In many cases an elongation of the suction line and capillary gives efficiency improvements.

The capillary itself has to be in good heat exchanging contact with the suction line for as long a part of total length as possible.

At high superheat, with good internal heat exchange, the theoretical COP of R290, R600a and R134a is higher than for R22. At very low superheat the COP of R290, R600a and R134a is lower than for R22. The R290 behaviour is similar to R134a, with respect to internal heat exchange.



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4.3
Evacuation

Generally the same rules for evacuation and processing are valid as for R22, R134a or R404A systems. The maximum allowable content of non condensable gases is 1 %.

Too high level of non condensables increases energy consumption because of higher condensing temperature and a portion of the transported gas being inactive. It can additionally increase flow noise.

4.4
Cleanliness of components

The specifications for cleanliness are generally comparable to R22 or R134a. The only official standard on cleanliness of components for refrigeration use is the DIN 8964, which also is used in several countries outside Germany.

It specifies maximum contents of soluble, insoluble and other residues. The methods for determining soluble and insoluble contents are to be modified for the actual refrigerant R290, but in principle the same limits are useful.

5.0
Service

Servicing and repair of R290 systems is possible for skilled and well trained service technicians. Please see note CN.73.C for details.

The equipment of the service technician has to meet the requirements of R290 in terms of evacuation quality and refrigerant charge accuracy. An electronic scales is recommended to control refrigerant charge to within the needed accuracy.

Local laws and regulations have to be taken into account also. It needs very careful handling because of the flammability of the gas, which is a potential danger during work on the refrigeration system.

Conversion of a R22, R502 or R134a system to R290 is not recommended by Danfoss, because these systems are not approved for flammable refrigerant use, so electrical safety is not proven to be according to the needed standards.

A good ventilation of the room is necessary and the discharge of the vacuum pump has to be lead to open air.

References

TS 95006	Refrigerators, food-freezers and ice-makers using flammable refrigerants, Safety Requirements, Ammendment to IEC 60 335-2-24, CENELEC, July 1995
CN.86.A	Driers and Molecular Sieves Desiccants
CN.82.A	Evaporators for Refrigerators
CN.73.C	Service on Household Refrigerators and Freezers with New Refrigerants
CN.60.E	Practical Application of Refrigerant R600a Isobutane in Domestic Refrigerator Systems
EN 60335-2-24	Safety of household and similar appliances Part 2: Particular requirements for refrigerators, food freezers and ice-makers

