Purdue University
Purdue e-Pubs

International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

1996

Recent Developments to Extend the Use of Ammonia

T. Tiedemann
University of Hannover

M. Burke
University of Hannover

H. Kruse
University of Hannover

RECENT DEVELOPMENTS TO EXTEND THE USE OF AMMONIA

T: Tiedemann, M. Burke, H. Kruse
Institute for Refrigeration, University of Hannover
Welfengarten 1a, 30163 Hannover, Germany

0. ABSTRACT

Based on the phase-out of CFCs and HCFCs and in view of the global warming concerns about HFCs the interest in ammonia as refrigerant is increasing. While ammonia has been the dominant refrigerant in industrial refrigeration plants of larger capacities it could not compete with CFC/HFC-systems in applications of small and medium capacities for economical and safety reasons. This situation is presently changing due to new developments in semihermetic compressors, soluble oils enabling an automatic oil return, and the use of aluminum for tubing with new soldering materials a test rig incorporating all these new developments, which also can be operated as calorimeter for compressors, has been built up.

In this paper experimental results regarding the semihermetic compressor, the oil return using dry-expansion evaporation with plate heat exchangers, and soluble oils will be shown. Experiences in using aluminum as piping material with new solders are discussed.

1. INTRODUCTION

The use of ammonia in industrial refrigeration is a well known, widespread, economic, and energy efficient technology utilized in many countries. Due to the challenge to use environmentally acceptable refrigerants and restrictions on the use of CFC and HCFC refrigerants, especially in Germany with a phase-out of R22 in 1999, ammonia presently is gaining increasing interest in air conditioning, for cooling in supermarkets, and in systems of small capacities.

For several reasons ammonia is presently not widely used in refrigeration systems of small capacities and further developments are necessary [Kau93, Nes94, Mol94]:

- Automatic operation: Small plants have to operate fully automatically since no technicians are available, as often is the case at industrial plants. Therefore, automatic expansion devices and an automatic oil return have to be developed, which are reliable and not too sophisticated and costly.
- Safety: Safety is an important issue since smaller systems often are installed where people who are not trained to handle with ammonia are working or living. This includes the minimization of the refrigerant charge, the use of tight connections, and hermetically sealed compressors.
- Economy: Small ammonia plants are not economical in construction compared to CFC and HFC systems. One main reason is the use of steel piping instead of copper which requires uncommon techniques like welding instead of soldering and flanging for the piping to be applied by the manufacturers. Other reasons are the limited availability of small components (heat exchangers, compressors, valves, etc.) designed for ammonia compared to mass produced CFC/HCFC equipment and the required safety installations.

Within a public sponsored research project an ammonia test plant has been built up in the laboratory of the Institute for Refrigeration at the University of Hannover for a cooling capacity of up to 30 kW. The purpose of this plant was to investigate some new concepts appropriate for ammonia as well as to determine the capacity of small ammonia compressors according to ISO 917. The main subjects of investigation in the first phase of an ongoing research project were:

- semi-hermetic compressor,
- automatic oil return by a soluble lubricant using plate-heat exchangers,
- aluminum as piping material.

2. TEST PLANT

In the laboratory an ammonia test plant has been built up using aluminum as material wherever possible (Figure 1). The plant has been designed to operate either as a conventional refrigeration cycle with plate heat exchangers as evaporator and condenser or as a secondary fluid calorimeter up to a cooling capacity of 30 kW. The purpose of this plant is to investigate some new concepts appropriate with ammonia as well as to determine the capacity of small ammonia compressors according to ISO 917.

Plate heat exchangers have been preferred to shell and tube heat exchangers in the test plant for several reasons:

- The refrigerant charge necessary is lower compared to shell and tube heat exchangers since types with enhanced heat transfer have not been developed for small ammonia plants.
- Shell and tube exchangers suitable for ammonia are more expensive than plate heat exchangers.
- The dimensions of plate heat exchangers are very small.
- The oil return using the soluble lubricant and the automatic control was expected to be most difficult with plate heat exchangers and should be investigated therefore.

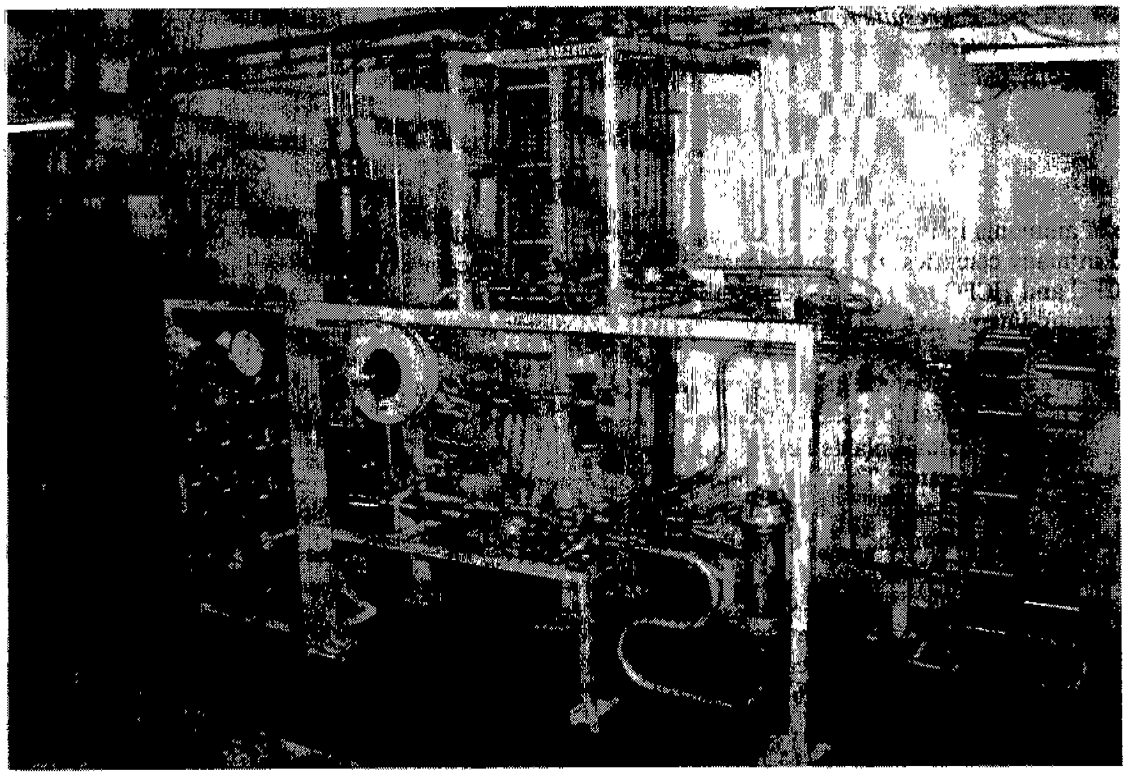

Figure 1: View of refrigeration plant using aluminum for tubing and plate heat exchangers as evaporator and condenser

3. SEMIHERMETIC COMPRESSOR

For safety aspects an ammonia refrigeration plant should be hermetically sealed in order to minimize the risk of a leakage. As conventional hermetic compressors cannot be employed due to the incompatibility between the copper windings and ammonia, different methods were considered [Kai95].

For already existing compressors [Lam93] the principle of a canned motor was preferred where the windings are hermetically protected against the ammonia by a steel tube between stator and rotor. But through the increased distance between these two parts the energy efficiency decreases.

Another possibility for ammonia compressors is to use a material for the windings compatible with ammonia. For ammonia compressors of larger capacities motors with aluminum windings already available [Wei91], but this also causes additional energetic losses due to the lower conductivity of aluminum compared to copper. For compressors of small capacity thinner wires would be necessary which are difficult to manufacture of aluminum.

Within this project an energetically favorable motor compressor has been developed by a German manufacturer, where the windings are covered by a lacquer resistant to ammonia. A sectional view of this compressor is presented in Figure 2. A special feature of this compressor is the motor cooling by air which is passing the covering at the outside surface close to the windings while the ammonia suction gas is directly entering into the compressor part.

First measurements were made with an already available open type small scale ammonia compressor (Figure 3) to exclude the effect of the motor, later the semihermetic compressor was used. The purpose of these investigations was to compare the volumetric as well as the COP of ammonia and R22.

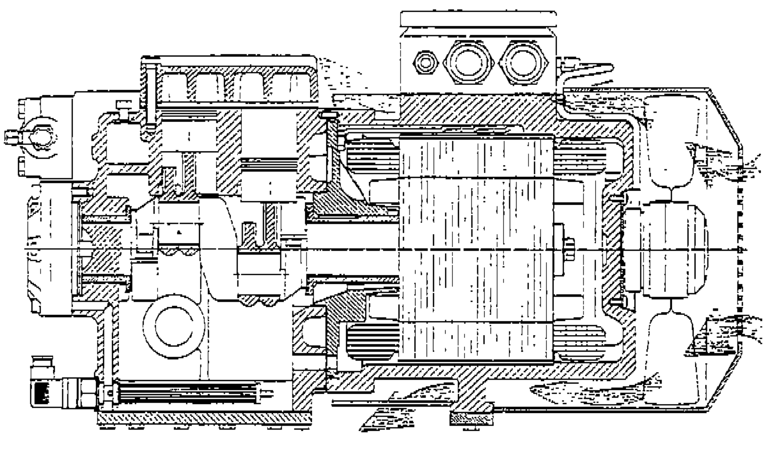

Figure 2: *Sectional view of semihermetic, air-cooled ammonia compressor*

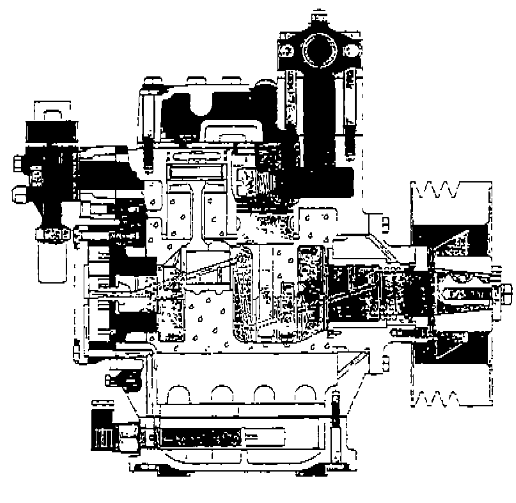

Figure 3: *Sectional view of open type ammonia compressor*

The volumetric efficiency at -10°C evaporation and +40°C condensation of this open compressor with ammonia is significantly lower than with R22 due to the increased pressure ratio of 5.37 compared to 4.81 of R22 (Figure 4).

Despite the lower compressor efficiency ammonia proved its favorable energetic behavior in higher measured values of cycle COP compared to R22 (Figure 5). From the thermodynamic data it can be expected that this energetic advantage of ammonia increases with higher temperatures of evaporation and condensation while the COP of R22 changes only slightly.

With the newly developed semihermetic compressor presented in Figure 2 first measurements have been carried out presently. In these tests the application limits due to the discharge temperature for increasing superheat have been determined (Figure 6). Further experimental investigations will be performed and the results will be presented at the conference.

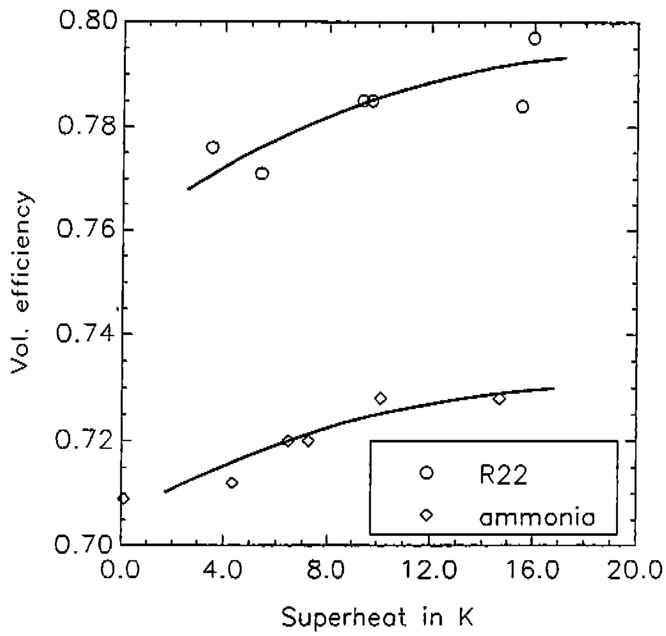

Figure 4: Volumetric efficiency of open type compressor with ammonia and R22

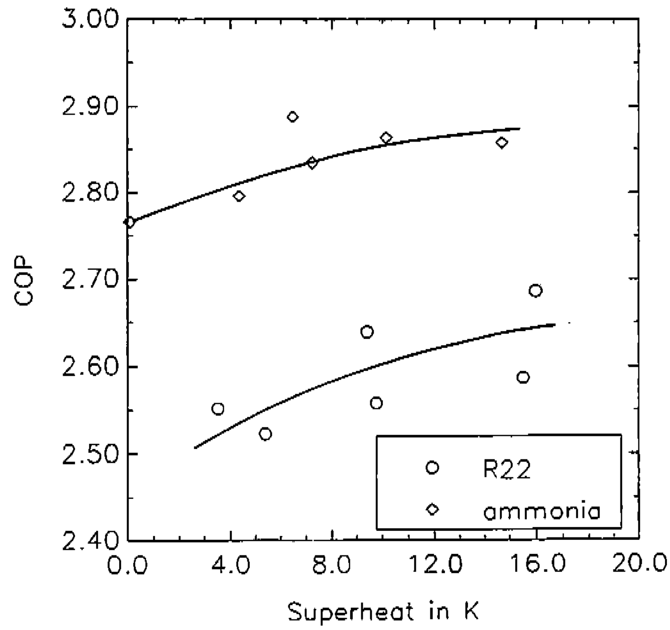

Figure 5: Measured COP of ammonia and R22 with open type compressor

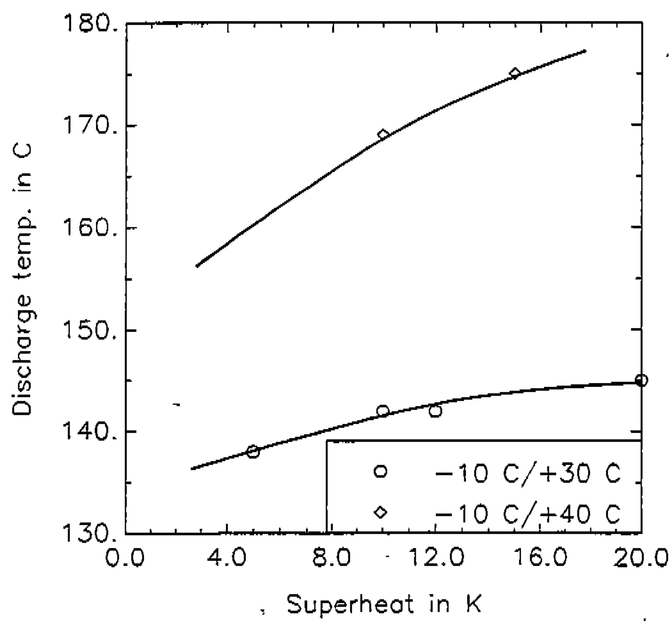

Figure 6: Comparison of discharge temperature vs. superheat of the semihermetic compressor

4. SOLUBLE LUBRICANT

The lubricant which basically is only necessary in the compressor will always be transported into the refrigerant cycle and finally accumulate in the heat exchangers, mainly in the evaporator. This results in a fouling effect causing a reduced heat transfer.

The lubricants traditionally used in ammonia systems are mineral oils and poly-α-olefine which are only marginal soluble with ammonia. Therefore, an oil separator has to be installed to minimize the oil content in the refrigerant flow. The small amount still reaching the evaporator is normally in large systems returned manually by technicians or by an automatic oil return device since these additional costs are marginal for those systems. In ammonia systems of small capacities a technician will not be available and additional costs are intolerable.

In a former research project at the Institute of Refrigeration a lubricant soluble with ammonia at the temperatures and compositions of a refrigeration system has been identified [Bur93]. The solubility of four investigated oils is shown in Figure 8. The investigations proved that the oil P3 is the most suitable for ammonia systems. This oil consists of an equivalent of ethylene oxide and propylene oxide compounds. If such a soluble lubricant is used, the oil is returned to the compressor by the ammonia flow because it has a rather low viscosity due to the solved refrigerant. Therefore, an oil separator or another mechanism to return the oil is no longer necessary. All soluble lubricants are based on polyalkyleneglycols (PAG) and are hygroscopic. Their lubricity is excellent, but is reduced significantly with increasing water content.

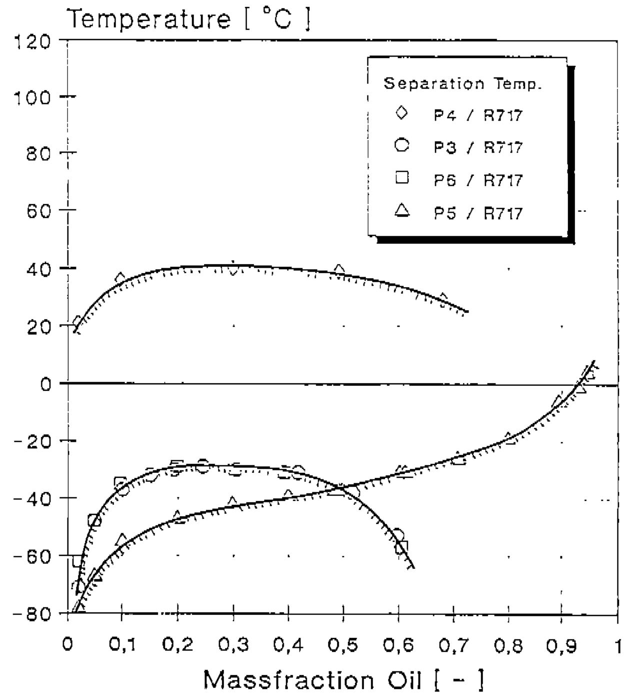

Figure 8: *Miscibility of new PAG oils in ammonia [Bur93]*

For the experiments with this new oil a plate heat exchanger has been used as evaporator. In order to investigate the oil return out of the evaporator the plate heat exchanger was modified in such a way that the plate which is passed at last by the ammonia can be looked into. With this heat exchanger it was observed that for superheating the ammonia more than 10-12K where only a small amount of refrigerant is solved the oil stagnated at the superheat section and in irregular periods is dragged along by a flood of liquid ammonia. By reducing the superheat to 5-10K a permanent oil transport by the evaporated ammonia could be achieved due to the low viscosity of the oil with still solved refrigerant while the cooling capacity increased significantly.

Further measurements of the refrigerant solved within the oil aimed to know the lubricant viscosity. With this data a maximum superheat depending on the evaporation temperature should be defined which enables an oil return from the evaporator to the compressor. In Figure 9 the mass fraction of refrigerant in the oil leaving the evaporator is shown for ammonia at the same evaporation temperature. The amount of solved refrigerant decreases with increasing superheat. Using this data and based on former measurements at the institute with this lubricants the viscosity was determined (Figure 9). On the first view the increasing viscosity at higher superheats seems to be contradictory, but looking at the mass fraction this increase is explained by less refrigerant solved which outweighs the normal decrease in viscosity at higher temperatures. These calculations coincide with the observations at the visible plate heat exchanger described earlier where it was noticed that the oil return stopped due to increased viscosity at higher superheats. Only for superheats below 10K the oil had a sufficient low viscosity to be returned. to the compressor together with the refrigerant flow.

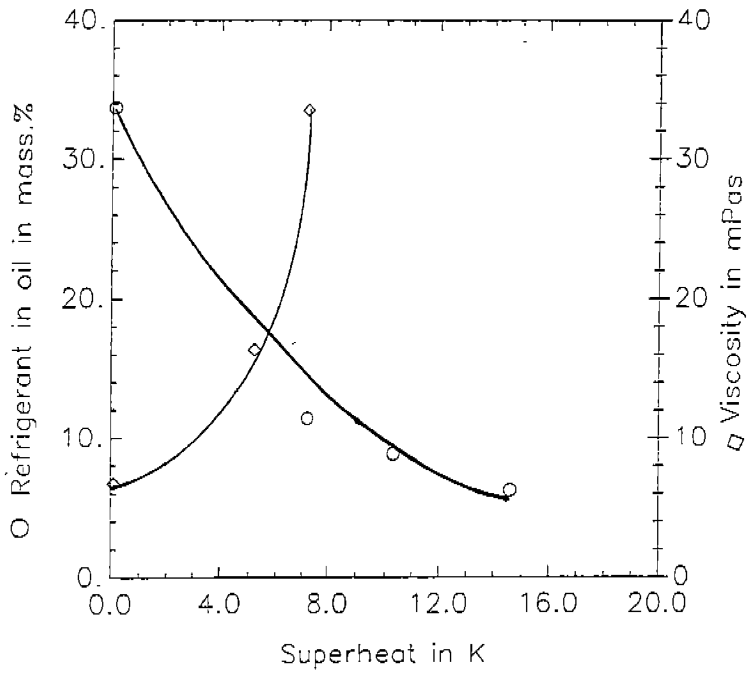

Figure 9: Measured mass fraction of refrigerant in oil and viscosity

5. ALUMINUM

One main reason for the higher costs for the construction of ammonia systems is the use of steel instead of copper piping, as it is used for CFC/HFC refrigerants, due to incompatibilities between ammonia and copper, brass, or other copper containing alloys. Therefore, the usual techniques like soldering, flanging, or bending cannot be applied and welding is necessary causing additional effort and costs. With aluminum there is an alternative material available at low costs (50% cheaper than copper tubes) for piping, fittings, and valves which can be used in the same manner as copper or copper alloys. If components made of aluminum are available and are used in a conventionally designed plant, the costs are similar to HFC systems.

At present, pure aluminum and the two aluminum-based alloys AlMgSi1 and AlMn1 are allowed in Germany to be used with ammonia. For the test plant built in the laboratory the alloy AlMn1 mainly consisting of aluminum and manganese which is stable with ammonia and water and can be formed like copper was used. Most connections were made by soldering since this is the usual technique used with copper for refrigeration plants. The solder consists of 88% aluminum and 12% silicon and has been used for connecting aluminum-aluminum as well as aluminum-steel connections which are needed at valves. Since the handling temperature of this solder has to be between 575°C and 590°C, which is only 50K below the melting point of the aluminum alloy, the soldering has to be performed very carefully. This is made more difficult, as the temperature is only indicated by a change in the consistency of the solder and the melting of aluminum starts not by a change in color like it is the case with copper. Due to the hygroscopicity of this solder the remainings from the soldering process have to be removed very carefully from the piping. Otherwise, corrosion might be initiated by the water contained in the refrigerant or the soluble PAG lubricant and corrosion can be initiated on other places by some particles transferred there. An improved workability can be expected by a non-hygroscopic fluxing material which is currently under development.

After nearly six months of operation some samples of aluminum tubes and soldered joint connections have been investigated by material researchers and no corrosion or destruction has been detected.

Besides the soldered joints aluminum tubes were connected by some removable connections while flange joints proved to be most appropriate. Even using these connections no problems occurred during operation of the test plant.

While in the laboratory plant no defects occurred at aluminum parts this was reported in some other ammonia plants where mainly the compressors were damaged due to breaks of aluminum parts at or near sleeve bearings. Material investigations showed selective corrosion and intercrystalline as well as transcrystalline brittleness. To investigate the low stability which may be caused by the coexistence of soluble hygroscopic lubricant, ammonia, water, and certain aluminum alloys further investigations are necessary.

6. SUMMARY AND OUTLOOK

Within a public sponsored research project a semihermetic compressor with a resistant lacquer to protect the motor windings has been developed and successfully tested and compared to a similar open type compressor. The soluble lubricant based on PAG proved an oil return without special features when the superheat was not too high. The disadvantage of this oil, as of other PAGs, is the high hygroscopicity causing possibly corrosion problems, especially together with soldering material when using aluminum.

Aluminum was used as piping material and the piping was done by soldering with new fluxing materials and bending of the piping in the same way as it is done now with copper. It turned out that the main problem in using aluminum is the limited availability of small aluminum components like valves, fittings etc. The durability of aluminum and its soldering connections under the various thermal and mechanical conditions and the compatibility with other materials and various refrigeration oils will be evaluated in another parallel research project mainly investigating material problems, which is likely to be started this summer.

The next phase of the current research project will focus on the development of small scale automatic expansion valves and the construction of pilot plants employing these new valves, various soluble oils, semihermetic compressors and further aluminum components like i.e. valves.

7. ACKNOWLEDGEMENT

The authors are indebted to the Deutsche Bundesstiftung Umwelt and to all participating companies for the sponsorship of this research project.

8. REFERENCES

[Bur93] Burke, M.; Kruse, H.: Solubility and Viscosity of New Oil/Ammonia-Systems. Proc. IIR Conf. 'Energy efficiency in refrigeration and global warming impact', Ghent 1993, p. 133-139.

[Kai95] Kaiser, H.: Ammoniak-Verdichter mittlerer und kleiner Leistung. Dresdener Kolloquium 'Neue Wege zum Arbeitseinsatz in der Kältetechnik', ILK Dresden, 1995.

[Kau93] Kauffeld, M.; Burke, M.; König, H., Hesse, U.: Neue Möglichkeiten für den Einsatz des Kältemittels Ammoniak. kk 10(1993), p. 712-722.

[Lam93] Lampugnano, V.; Kawamura, N.: New Approaches to Ammonia System Designs. IIAR 15th Annual Meeting, Vancouver 1993.

[Mol94] Moller, L.B.; Minds, G.; Nielsen, O.R.; Nyvad, J.: Demands on and Development of Small Ammonia Plants for Direct and Indirect Cooling. Proc. IIR Conf. 'New Applications of Natural Working Fluids in Refrigeration and Air Conditioning', Hannover 1994, p. 663-672.

[Nes94] Nesje, O.M.: Ammonia in Small Refrigeration Plants, System Design - Practical Experience. Proc. IIR Conf. 'New Applications of Natural Working Fluids in Refrigeration and Air Conditioning', Hannover 1994, p. 673-682.

[Wei91] Weissenborn, P.: Ammoniak-Träume werden wahr. kk 2(1991), p. 110-122.