Technical Session VI

Report about the Papers

on

Refrigeration

by

Prof. Dr.-Ing. Dr. h.c. H. Kruse
University of Hannover, Germany

- Rapporteur -

Paper P2
Thermal Energy Storage for Supermarkets

This paper deals with supermarkets where refrigeration is needed for chilled and frozen food and air conditioning is needed for the supermarket HVAC system. In today's supermarkets, the trend is to use HFC-404a in the refrigeration plant and HFC-134a in the chiller plant. Whereas refrigeration contributes to around 50% to the energy consumption of a supermarket, so does the HVAC system with around 20%. Both have a peak at daytime during opening of the supermarket, whereas the loads at nighttime are much lower, for the food refrigeration plant because of the blinds on the cases.

The peak demand for the HVAC system could be flattened by an ice storage system, but in order to produce ice during nighttime, the evaporation temperature has to be lowered resulting consequently in a reduced COP during ice production. The idea of an integrated thermal energy storage for supermarkets is that the ice generation can be fulfilled during nighttime by the food refrigeration system running already with a lower evaporation temperature. By this, the number of air conditioning chillers can be reduced or even completely eliminated. So, the charge of the HVAC system can be reduced and the direct contribution to global warming decreases. If looking onto the hourly carbon dioxide emission it can be stated that because of using different types of power plants during the nighttime the emission rate of carbon dioxide also is lower. Therefore, by shifting the electricity used for the air conditioning system to the nighttime in order to produce ice for the thermal storage system, the demand can be flattened, but the total potential of CO_2 savings is only around 3% in summer time and 0.2% in winter time.

Therefore, an additional approach should be used to generate ice slurry for the thermal storage and use this secondary coolant medium also for the food supermarket systems in order to decrease the charge of the food refrigeration system. With this integrated approach, the total equivalent warming impact TEWI of the supermarket system can be reduced by decreasing the charge of the water chiller plant when using thermal storage with ice generated by the refrigeration food plant during the nighttime and furthermore applying ice slurry as thermal storage medium which not only can serve the HVAC system, but also the refrigeration need for the supermarket as well as directly in the medium temperature range as also indirectly as condensing cooling fluid for the low temperature package units serving the frozen food cabinets and the frozen food cold store.

Paper P6
Dynamic Simulation of Central Chilling System of a Large Office Building

For large office buildings dynamic control strategies for the central chilling systems are a tool to minimize the total energy consumption. Buildings in Hong Kong are the largest energy consumers, and therefore the example of an office building in Hong Kong is used to develop a dynamic simulation model for such a system. Those systems because of the limited fresh water resources there and the government restrictions for using cooling towers have resulted mainly in the usage of seawater cooling systems. Variable speed seawater pumps are used to provide the seawater in order to cool the condensers of the water chillers. On the other hand, also variable speed pumps for the chilled water provide the building air handling units with the cooling media. Both water pump types are controlled by moderating the frequency using a frequency inverter of each of the pumps.

In order to test and upgrade the online control strategies of such a system, dynamic models for the components of the systems like centrifugal chiller, heat exchangers, seawater and chilled water network, cooling coil, actuator, sensor, variable speed pump, and frequency inverter, etc. have been developed to simulate the realistic performance of the system. This has been done for the evaluation of the online control performance in different seasons. Furthermore, the simulation concerned especially the control strategy for the online optimal seawater pressure set point reset in order to minimize the energy consumption.

In the paper the system is explained and furthermore the equations for the dynamic behaviour of the various components above mentioned are described.

The simulation performance is proven for four different cases, one summer and one winter case and two middle-term cases. The optimal pressure set point is directed to minimize the total power with respect to the seawater pressure difference across the heat exchanger. So, for the four cases evaluations of the model were performed showing a very small deviation between the electricity consumed for the optimal reset strategy and for an ideal control ranging from 0.01% to 0.08%. Comparing the optimal reset strategy with a maximum or minimum speed of the pump set for the various cases, an energy saving ranging from 1.7% to 14.31% according to the different cases could be achieved. So, it could be shown that the developed simulation programme for the dynamic response of a central chilling water system to the online control strategy by using frequency moderated inverter pumps for the seawater and the chilled water system is a good tool to optimize the control system in order to save energy.

Paper P59
Motor Current Features in HVAC/R Equipment Diagnostics

The paper deals with the possibility to use the signal of the motor current of equipment for air conditioning and refrigeration units as for instance the compressor motor or the fan coil motor in order to find out design misbehavior. The current as it evolves moment by moment is regarded as an information source for this purpose. Analysis of the signal is done either in terms of its actual values as a time domain or

after it has undergone a Fourier Transformation and is decomposed into components at all frequencies (frequency domain). So, various effects influencing a misbehavior of a refrigeration or air conditioning system can be predicted when analysing such a current signal.

Based on a lot of experiments with an air-conditioning unit, the authors show how the signal changes if for instance filter clogging can be stated or fan or impeller disbalance occurs. Both peaks of the rotor speed and the slip signal show changes according to these misbehaviors of the system.

Further experiments were done on a centrifugal pump, where motor shaft skewing has caused a second peak representing the rotor speed, whereas with a shaft which is not skewed shows only a frequency peak in the current spectrum which is caused by the interaction of the impeller and the fluid.

In order to analyse furthermore the current signal, the influence of various refrigerant charge amounts for a split air-conditioning system is investigated concerning the pseudo-slip signal of the current, the root mean square current, the maximum current, and the timing of compression. Here, various dependencies have been stated experimentally, but a clearer relation for the interaction cannot be given at this time. Therefore, the future work besides investigating various other effects like these discussed will be directed to multi-evaporator systems or the determination of evaporator icing levels, non-piston compressors for diagnostic and control systems. Also it is important to elaborate the state of the theory, because only with this theoretical work a relation between the observed effects and the causes can be explained.

Paper P99
Frost Prediction on Evaporator Coils of Supermarket Display Cabinets Using Artificial Neural Networks

The frost formation on evaporator coils is especially unfavourable in supermarket display cabinets because not only the energy to defrost the coil is increasing the energy consumption, but also the increasing coil surface temperature during defrost is increasing the package temperatures of the chilled or frozen food which then has to be cooled down again. Although in the past different demand defrost strategies have been proposed, none has found wide acceptance in the food retail industry due to poor reliability and high capital costs.

In the paper it is proposed to initiate demand defrosting by using an artificial neural network which should predict the rate of frost formation on the coil by monitoring data online and predicting the performance of the coil as a function of the monitored parameters. As neural networks are trained to learn solutions, they should be able to learn the relationship between the amount of frost accumulation and various parameters, such as i.e. the refrigerant and air temperatures and pressures as well as room temperature and relative humidity. Using the normally available various

measured data in a supermarket, the aim can be to predict the amount of frost formation by such a neural network, which relates these measured parameters to the frost formation.

Tests have been done at an experimental test facility with two display cabinets, one serving as a test cabinet and the other one as an extra load cabinet for defrosting purposes, and in an actual supermarket which was instrumented to record additional parameters as especially the amount of condensate collected after defrosting. It could be shown in this supermarket that, depending on the difference between summer and winter conditions with relative humidities of 25 and 40% respectively and nearly the same internal temperatures of the cabinets, the condensate after timed defrosting of each six hours differs by 100%. Therefore, when defrosting frequency could be halved in winter time a lot of energy could be saved. The results obtained in the laboratory and related to space temperature, relative humidity, and number of cooling hours were used to train an artificial neural network to learn the relationship between these parameters and the amount of condensate obtained after defrost. This amount is depending on non-linear functions of many variables. In a neural network the number of free parameters in such models typically only grow linearly or quadratically, whereas when using a mathematical polynomial approach, the dependency is growing exponentially with the order of the polynomal function.

Therefore, artificial neural networks seem to be a good tool to be applied in supermarket systems for demand defrosting purposes in order to save energy and further work will be carried out on this topic taking into account further operating parameters, such as refrigerant pressures, temperatures, air velocities, and coil surface temperatures in order to determine indirectly from such measurements the rate of frost formation on the coil. Then it would be possible to predict the necessary frequency of defrosting from these already available parameters in a supermarket system by employing an artificial neural network.

Paper P114
Modelling the Effects of Oil on Evaporator Performance

In vapor compression systems with positive displacement compressors the working fluid always consists of the refrigerant and a certain amount of oil of up to 10% by mass. This oil especially affects the heat transfer inside the evaporator. The heat flux available which normally is low in air cooling heat exchangers determines the importance of the oil during heat transfer.

In order to investigate theoretically this effect of oil on the evaporation of refrigerants inside tubes, the paper describes a model taking into account the thermophysical properties of the oil-refrigerant mixtures, the local conditions where the corresponding properties are calculated for the liquid and gaseous phases independently of being in thermal equilibrium or not, and a quasi stationary heat transfer process without time dependency. The model takes into account the various flow patterns due to the acceleration of the gaseous phase formed inside horizontal

tubes during vaporization and additionally the effect of the oil upon these flow patterns due to higher surface tension and viscosity of the liquid phase. The important parameters are the degree of wetting of the tube wall and the heat flux initiating nucleate boiling on the wetted surface from a certain amount on. For the most complex case of the partially wetted wall an electrical network anology was used for the mathematical treatment of the circulation problem. Whereas the energy balance for this network is given by a set of equations, the presence of oil in solution increases the complexicity of the transport processes by promoting the formation of foam. The mathematical model takes into account the two phase flow behavior and the thermophysical properties of the oil-refrigerant mixture and is described in the paper. With this model it is possible to obtain detailed local information along the pass of the fluids inside the evaporator on the various parameters like void fraction, heat transfer coefficients for the two phases, fraction of wetted tube wall, temperature difference, etc. For a variation of the input values like oil mass fraction, mass flux and heat flux, oil viscosity, calculation results are presented for a model case in order to show the applicability of this developed simulation model for the effect of oil on the evaporator performances.

Paper P127
Design and Simulation of Finned-Tube Heat Exchangers Using Pure and Mixed Refrigerants

In the paper a simulation model for finned-tube heat exchangers of the evaporator or condenser type is described which divides the whole heat exchanger into elements and using local values of properties and heat transfer coefficients. Models of this type have already been presented by various authors, but none of their programs could handle mixtures with the exception of Haselden's model for both evaporator and condenser design. That model was proven by experiments with a R22/R142b mixture and used to design novel heat exchangers for air conditioning duties using refrigerant mixtures.

The authors present in detail their new heat exchanger model they developed both for condenser and evaporator duties, also taking into account refrigerant mixtures as working fluids. Here, the main changes of the calculation involve the refrigerant properties of mixtures, the initiation of the refrigerant and air temperature profiles, the calculation of temperature and vapor quality at the exit of each tube element in the two-phase region, and the condensing and evaporating refrigerant heat transfer coefficients for mixtures. The thermodynamic and transport properties of ternary and binary mixtures based on R32, R125, and R134a were calculated with cubic equation of states and refrigerant manufacturers' data for the transport properties, respectively. The calculation for the mixtures starts with an equilibrium calculation to determine liquid and vapor phase composition, calculating from these the transport properties for each phase. The pressure drops are then calculated using the correlations for pure components and mixtures properties. Furthermore, refrigerant and air heat transfer coefficients yield heat transfer rates which are used in energy balances for both the refrigerant and air side to calculate the enthalpies at the exit of the tube elements. For

the heat transfer coefficients of refrigerant mixtures, the available data in literature were evaluated and the procedures recommended by Bell and Ghaly for the condensing heat transfer coefficient and by Bivens and Yokozeki for the evaporating heat transfer coefficient were used correspondingly.

Experimental investigations were conducted first with water in the tubes in order to characterize the fins and the measured data were compared with the simulation model results. An accordance within 2-3% under dry air conditions and under 5% for humid air condensing on the fins can be stated. For the evaporation and condensation cases comparisons were made using R22 as working fluid for smooth and grooved tubes and discrepancies between the simulation results and the experiments under wet conditions are lower than 5% and even better for dry conditions for evaporators with smooth tubes. For condensers, the predicted duty is consistently 5% below the measured one. Also the results for grooved tubes can be predicted within 5% accuracy or even better when special coefficients for this design are identified and used in the calculation. The same holds for condensers using the Cavallini method as proven for grooved tubes. Very regrettably, no experimental validation could be made for the calculation of both evaporators and condensers using zeotropic refrigerant mixtures. Only a comparison between both calculated results for R22 and R407C in the case of evaporators and condensers both could be made. The calculated results show furthermore similarity to the experimental results obtained by Ebisu and Torikoshi with both fluids, so that the conclusion is drawn that the developed simulation program is also able to predict the heat exchanger duty when using zeotropic refrigerant mixtures.

Paper P128
Design and Simulation of Heat Pumps and A/C Equipment Using Pure and Mixed Refrigerants With Modular Modelling

The paper describes a refrigeration cycle model for heat pumps and refrigerating equipment which is similar in the structure to other models developed earlier by Oak Ridge National Laboratories, National Bureau of Standards, and Purdue University. The novel features of this model are the strategy and formalism adopted in the program development which leads to a flexible and evolative structure because by the modular structure the whole refrigerant cycle can be built up by using the specific component models developed. Therefore, a user can actually build up a machine from component libraries that includes several types of heat exchangers, compressors, and expansion devices. On the other hand, due to the simplicity of the model, the component modules must be calibrated via actual test data on the one hand, but therefore very accurate results can be obtained on the other hand.

The developed simulation model was validated with experimental results for an air-to-air split unit over a range of external conditions where discrepancies smaller than 5% could be obtained for the aimed results of evaporator and condenser capacity, compressor power, and COP. The model was also checked against the experimental results on a water chiller using R22 and R507, and it can also be stated that the main

results like condenser duty, compressor power, mass flow rate, and discharge temperature lie well within 5% of the deviation lines. So, another simple simulation program for heat pumps and refrigeration units has been presented and experimentally validated.

Paper P129
Experimental Evaluation of Some Proposed R22 Alternatives in Chillers and Unitary A/C Equipment

For the substitution of R22 various alternatives are investigated world-wide, mainly as a short-term solution R407C which is a zeotropic refrigerant mixture consisting of R32, R125, R134a, and R410 in the versions of R410A and R410B with a very slightly different composition of the binary mixtures of R32 and R125. Meanwhile the chemical manufacturers have agreed upon R410A with a composition of 50% mass fraction each. As in other countries like the AREP program in the United States, also in France an investigation is underway to evaluate the performance of the various alternatives to R22. The paper presents especially R407C and R410B. These fluids together with the baseline refrigerant R22 were tested in three devices, namely a 15 kW water chiller no. 1 which operates in the cooling mode only and has a counter current plate evaporator, a scroll compressor, and a plate fin-and-tube air cooled condenser. Water chiller no. 2 with a capacity of 30 kW is equipped with a reversible circuit for cooling and heating mode employing a reciprocating compressor, a spiral plate evaporator and a four circuit air cooled spin fin condenser, each in two parallel refrigerating circuits. Furthermore, a room air conditioner of 6 kW was used as a reversible split system composed of a reciprocating compressor, capillary tubes, an indoor finned-coil unit with grooved tubes arranged in cross flow, its circuit approximating the counter flow and by intermediate tube branching trying to keep vapor and liquid phases together by increasing the allowable cross sectional flow area, which holds also for condensation the optimum thermodynamic conditions. The outdoor unit has smooth tubes in cross-flow arrangement but also approximating counter-flow by adequate circuiting.

The test results in the different units comparing R22 and R407C show that with this alternative refrigerant in the first chiller capacity and efficiency can be maintained within ±5%, whereas in the second chiller without counter-flow heat exchange the capacity was decreased by 16% and the efficiency losses ranged from 8% to11%, mainly caused by overall heat transfer coefficients which were decreased for the evaporator by 30% and for the condenser by about 10%. For the reversable room air conditioner, the capacity and efficiency with R407C was maintained practically at the same level with only a marginal degradation of 4% and 2%, respectively. In the heating mode with no cycling operation also capacity and efficiency were more or less maintained with ±1% and a maximum of 5%, respectively. However, under cycling conditions because of a shorter frosting period for R407C the heating duties were improved by 18% leading also to a better performance although the setting of the control devices caused more frequent cycle reverses.

For the zeotropic mixture it could be seen by these tests that by using counter-flow evaporators in the water chiller or trying to keep the slip between vapor and liquid as low as possible by adequate heat exchanger circuiting for the indoor and outdoor unit of the room air conditioner and employing grooved tubes which have beneficial effects on heat transfer because of increased turbulence and mixing, good results for the substitute R407C compared to R22 at nearly the same level can be achieved. In case of no counter-flow heat exchange in contrary losses in capacity and efficiency caused by lower heat transfer coefficients could be stated as shown with water chiller no. 2.

Additional tests conducted on this second chiller with R22 and R410B using a 20% smaller sized compressor gave results in cooling duty changes from +8% to -5% and efficiency decreases from -7% to +12%. Despite rather high heat transfer coefficient degradation at small flow rates of more than 25% for the evaporator and between 4% to 15% for the condenser, the increased compressor efficiency of 8% higher than for R22 leads to a not too dramatic reduction of the EER. So, in general the paper confirms the experience that for special alternatives with their individual thermodynamic properties special designs are needed to achieve a reasonable efficiency when substituting R22.

Paper P232
Safety Features of HC Refrigerants in Car Air Conditioning

The paper discusses the possible application of hydrocarbons especially the 50% mixture of isobutane R600a and propane R290 in order to replace the ozone depleting substance R12 in car air-conditioning systems. The discussed accident scenarios for dangerous conditions in the passenger compartment are based on three simultaneous events, first a leaking fracture has to occur in a refrigerant line within the passenger compartment, second, a flammable mixture has to be formed which has a concentration above the lower explosion limit, and third, an ignition source has to be present. Whereas fractures of all kinds of sizes can occur in a vehicle during normal operation caused by fatigues, vibrations, or accidents, ignition sources as has been investigated can only be the matches and butane lighters, but not fan motors, switches and cigarette lighters of the car.

In the paper, the two discussed systems of automotive air conditioning units having either a TX valve or an orifice tube as throttling device are investigated concerning the accident scenario by using simulation programs supported by adequate experiments on various automotive air conditioning systems of individual cars.

The results show that systems with an orifice device having a suction accumulator for the refrigerant can cause all the refrigerant of the suction side to enter the passenger compartment in case of a line rupture which in the worst case can lead to a five minutes time above the lower explosion limit inside this compartment. Explosion can occur if in this time a match or a butane cigarette lighter will be employed. The good agreement between experimental and simulation results shows that the influence of

the desiccant and the oil in the suction line accumulator does not influence the leak scenario remarkably.

For systems with thermostatic expansion valves the scenario depends on whether the expansion valve is located within the passenger compartment or not. In the first case, the fracture of the liquid or the vapor line may influence the scenario differently, whereas in the second case only a fracture in the vapor line is of interest. The results for those systems have been examined, using an actual system, removing it from a car, and running a set-up in the laboratory from which the refrigerant was released both from the liquid and vapor line. The results show that almost any fracture size in the liquid line causes all of the refrigerant to enter the passenger compartment instantaneously. For a certain car this was not sufficient to obtain a flammable mixture within the compartment. Fracture in the vapor line causes liquid refrigerants penetrating the TX valve from the liquid to the vapor side and entering the passenger compartment. Due to the sudden pressure drop in the vapor line when a fracture occurs, the TX valve fully opens and all the liquid line refrigerant of the high pressure side is released into the passenger compartment. With this scenario model calculations have been done showing that depending on the car model and the ventilation rates always during short time the lower explosion limits are reached.

Paper P267
Miscibility, Solubility, and Viscosity of Alternative Refrigerant/Lubricant Mixtures - Experiments and Modelling

In the paper it is indicated that new measurements of miscibility, solubility, and viscosity for mixtures of pure and mixed refrigerants R32, R123, R125, R143a, R134a, R404A, R407C, R410A, R410B, and R507 with polyolester and polybasicester lubricants have been made. The measurement apparatusses are described first in the paper consisting mainly of a constant volume cell for solubility measurements, a vibrating tube density meter for the density, a capillary tube viscometer building up the necessary pressure difference by a mercury column, and a miscibility measuring cell consisting of a glass tube within a thermostatic liquid base.

A lot of measurements with the above mentioned refrigerant and lubricant mixtures have been done and stated, but regrettably, these measuring results are not given in tables but only as very limited examples in diagrams without data points. So, the paper describes mainly the test method, but does not give values of the experimental results.

For the thermodynamic modeling of the data, various approaches have been used because of the difficulty of calculating the thermodynamic oil behavior in a mixture with the refrigerants. For the solubility model, the approach of Yokozeki was used which is based on the Redlich-Kwong-Soave equation of state and requires four adjustable parameters and fits the experimental data within a standard deviation of approx. 1.5% in pressure. For modelling the vapor liquid and liquid-liquid equilibrium behavior of the refrigerant-lubricant mixtures, the used approach is to

apply a standard equation of state like RKS or a virial equation of state with a modified interaction parameter. The parameters of the equation of state and the binary interaction parameter for the lubricant-oil mixture are found by minimization in pressure and composition using the same equation of state. So, experimental data are needed to present more or less an approximation equation for the calculated equilibrium curve like that one in the liquid phase between miscible and immiscible region. Also the viscosity modeling is supported by experimental data and uses the approach of Yokozeki and is fitted to experimental viscosity data for R32, R125, and R410. With this approach a deviation of 5-10% can be obtained. When using an excess viscosity function for different refrigerants, which depends on the polarity of the refrigerant and the mutual solubility of refrigerant-lubricant mixtures, a deviation of 5-7% could be stated. Also a free-volume model has been applied achieving together with the experimental data for calculating the parameters an average deviation of approx. 8% for more than 50 refrigerant-lubricant mixtures. So, in conclusion, the paper presents mainly the method of the measurements, not the measurement results and describes the applied theoretical models for calculating the miscibility, solubility, and viscosity of alternative refrigerants supported by measured data points.

Paper P271
Testing and Modeling of Bisplit Refrigeration System Analysis of the Refrigerant Charge Effect on the System Global Performance

The authors describe the test equipment and the test results when investigating a bisplit refrigeration system with two evaporators and two thermostatic expansion valves but one compressor and one condenser. The test equipment in detail is described and from that adequate balances around the individual components are made in order to evaluate the component behavior. Balance errors for the various components in the region between 3% and 5% could be stated which were lower when taking into account the circulating oil. Since in these tests the oil flow rate was not measured, the estimation of the relative error with and without oil was based mainly on an assumed optimal oil-refrigerant ratio of 1.5% and it seems to be important that the oil effect should be taken into account in all energy balances when actual flow rate estimations are required, as can be seen by the difference in the relative errors with and without oil.

The tests were run in two series, the first one consisted of 31 tests on the bisplit system under different load conditions, the second run of 24 tests varying for the same system the refrigerant charge from 1.7 kg to 2.4 kg. In the first tests the results show the behavior of the thermostatic expansion valves showing at one of them the hunting effect, on the other the effect of liquid leaving the evaporator. For the second series of tests, the effect of charge was investigated and presented as far as subcooling, superheat, refrigerant flow rate, and total refrigerant capacity as well as COP is concerned.

The explanation of the results is not discussed in detail, but only shown that an under- or an overcharging of the system results in a drop in flow rate and capacity, whereas the same tendency cannot be stated clearly at the COP.

At last, the paper presents a modelling of the bisplit system, using the modular modelling simulation which was elaborated by another research center some years ago and which is applied to the various components of the systems like the two evaporators, the thermostatic expansion valve, etc. Regrettably, the model was not extended in order to evaluate by simulation the effect of the refrigerant charge, so that only the relations concerning the refrigerant capacity and the superheat between model and experiment could be stated. Whereas the capacities for both evaporators lie in the most cases within the -10 to +10 error lines, the superheat can be simulated as compared to the measurements at very high superheat of more than 10 K with a relative error not exceeding 15% of the temperature difference, but at the normal superheat values between 5 and 7 K a very scattered correlation between modeled and measured superheat can be stated. So, the conclusion is that still work should be done in order to improve the model.

Paper P284
Domestic Refrigerators Energy Efficiency Calculations Through Heat Transfer Analysis in the Laboratory and on the Computer

The paper describes experiments and computer simulations of domestic refrigerators in order to predict their behavior under various test or standard conditions as well as under design changes like an increasing wall insulation thickness. The temperature profiles and the heat flux are measured at the corpus of a refrigerator with a chilling and a frosting cabinet where the temperatures are taken by thermocouples and the heat flux by special developed heat flux meters. In order to investigate the thermal behavior of the corpus of the refrigerator a heat source inside the refrigerator is applied in order to keep the internal space of both cabinets around 66 °C at an ambient temperature of 22 °C. Despite the different heat flux directions in the heating or cooling mode and the different convection directions inside the refrigerator it is assumed that this does not affect very much the heat transfer behavior of the refrigerator itself, so that the results are compared with refrigerator running results when using the heat transfer results and calculating from them the results for the cooling mode.

So, a computer simulation was made using the experimental heat transfer results in the above mentioned heating mode and transferring them to the cooling mode with internal temperatures of 4°C and -16°C for the chiller and the freezer compartment respectively at an ambient temperature of 22°C. By this conversion, taking into account a COP of the compressor of 1.1 and an electric motor efficiency of 88%, a comparison is made to experimental energy measuring values for some considered refrigerators. By this method, only a rough approximation of the refrigerator energy rating can be achieved as compared to the measured rating with errors up to 27%. This seems to be not very accurate and is explained by the design of the individual

refrigerators which partially have their freezers located below the cooler and the others in the opposite way. But one of the latter also shows an error of 23%, so that it seems that the simulation is not very accurate for a prediction of the energy consumption. This is understandeable since an average of the COP of 1.1 independent of the evaporating and condensing temperatures is assumed for calculating from the heat load onto the refrigeration cycle the compressor power input and furthermore, because any cycling is neglected. So, in conclusion the work done some years ago consisting of thermal conduction measurements at the refrigerator corpus, and calculating from that the power consumed by the compressor shows only very limited agreement with experimental results. Therefore, the method should be refined furthermore in order to get better agreement between simulation and experimental results concerning the important energy consumption of refrigerators.

Paper P338
Transient Behavior of a Vertical Plate Evaporator for Ammonia

In this paper the transient behavior of an evaporator for an absorption refrigeration machine is simulated. The simulated evaporator is a plate heat exchanger with vertical wavy metal plates. The inlet for the refrigerant is at the top of the heat exchanger, the outlet is at the bottom. The secondary refrigerant flows in counter-current to the refrigerant. The refrigerant is ammonia.

For the model, the heat exchanger is divided into several elements (one dimension geometry) with own inlet and outlet parameters. The thermodynamic and physical properties are constant within an element. The plates are simulated as plain walls. The model of heat exchanger includes a dry boiling zone in the evaporator. For that purpose a special procedure for computing the total wetted lench of the evaporator was developed. These assumptions lead to a set of ordinary differential equations. The set of equations is solved numerically. With the program the mass flow rate density and the temperature of the refrigerant as well as the mass flow rate density and the temperature of the secondary heating fluid can be computed as a function of time and space. Also the pressure of the evaporator can be calculated as function of time. For these results inlet parameters are required: The mass flow rate density of the secondary heating fluid and of the refrigerant at the inlets, the temperature of the refrigerant and the secondary heating fluid at the inlets, and the refrigerant mass flow rate going to the absorber.

In order to show the performance of the program, the authors give three examples of possible time dependent simulation results. Variation of the refrigerants' mass flow rate, variation of the heating fluids' inlet temperature and the beginning of the evaporation process.

Paper P356
Effect of Using R-134a on a Domestic Refrigerator Originally Designed for R12

The paper describes the test results when using R-134a in a refrigerator originally designed for R-12. For this purpose two new identical refrigerator/freezers produced in Egypt were tested, using in one of them R-12 and in the other one R-134a. The test equipment and setup is described and it is explained how one of the refrigerators has undergone a retrofit procedure converting it from R-12 to R-134a by draining the compressor oil, flushing the cycle with ester oil, and changing the oil once after 15 minutes and again after 30 minutes of running time. By this procedure it is expected to remove all traces of the oil.

Besides equipping the refrigerators with five thermocouples and two pressure gages to measure the temperature and pressure of the refrigerant cycles of each refrigerator, also two current transducers were used together with the voltage measurements for

the estimation of the electric power input of the compressors. By using the adequate thermodynamic property data from adequate sources employing two computer programs for R-12 and R-134a, the results of the measurements at steady-state conditions after several on/off cycles could be evaluated. Results of motor current, evaporator and condenser exit temperature, compressor power consumption, cooling capacity, heating capacity, and mass flow rates of refrigerants were given as time history lines. The results from these tests show an around 4% less COP for R-134a as compared to R-12 and, furthermore, cooling and heating capacities 22-25% lower than for R-12. By these results it can be confirmed that changing a certain design of a refrigerator from R-12 to R-134a can cause a decrease in capacity and efficiency. The question is if the retrofit process was adequate enough in the flushing procedure in order to avoid traces of mineral oil be kept in the cycle and decreasing by its insoluble behavior with R-134a a decreasing heat transfer and hence capacity.

Paper P360
Ternary Zeotropic Mixture with CO_2 Component for R-22 Heat Pump Application

The paper presents investigations of a ternary mixture consisting of R-32 and R-134a together with a small amount of CO_2. The mass fraction of this mixture R-744/32/134a is 7/31/62% and shows in simulations using the Cycle 11 Model of NIST promising results.

The use of CO_2 in mixtures with halocarbons has been proposed already earlier by other authors and seems to be evaluated in this presentation experimentally the first time. For this purpose, a test facility for a heat pump was used consisting of two identical heat pump systems connected to the same heat sink and heat source loops. The evaporators and condensers consisted of tube-in-tube counterflow heat exchangers in order to make use of the temperature glide of the refrigerant mixture to adopt it to the temperature glide of the water loops in evaporator and condenser. An electronic expansion valve was used to control the superheat of the vapor leaving the evaporator and frequency transducers for controlling each compressor speed. With a data acquisition system for a personal computer 106 temperatures, 10 pressures, 4 water flows, 2 liquid refrigerant mass flows and 2 compressor power inputs were measured. For accurate compressor power measurements also a torque meter and RPM readings provided by this device were employed. The refrigerant mixture composition was measured by means of a gas chromatograph and samples were taken from the liquid line and the compressor discharge line.

Two kinds of tests were done, namely using the drop-in case, or having constant capacity when changing from R-22 to the investigated ternary mixture. The capacity was around 90% higher and the COP 2.5%. The constant capacity comparison with the same capacity of the ternary mixture as for R-22 shows for the mixture a COP exceeding that of R-22 by nearly 10%. In order to match the same capacity with the high pressure ternary mixture, the speed had to be decreased from 1500 rpm for R-22

down to 1185 rpm for the ternary mixture. The high COP of the ternary mixture was achieved because of good glide matching of the water and the zeotropic mixture which could be shown by the thermocouples along the heat transfer path, the good transport properties and the low modular heat capacity. Therefore, it can be stated that employing carbon dioxide as a component is interesting, but only for replacing R-22 for low temperature heat pumps. For newly designed heat pump systems, it could be a good choice because of an almost 10% higher COP as compared to R-22.

Paper P369
Potential of Non-Azeotropic Refrigerant Mixture as Working Refrigerant in Hot Water Heat Pumps

In the paper the improvement of the COP by using a non-azeotropic refrigerant mixture is investigated in comparison to R-22. The mixture used for the theoretical investigation consists of R-22 and R-142b in various concentrations.

First, the design of a pure fluid heat pump with R-22 is explained using various literature sources for calculating the individual components like heat exchangers, etc. For verification and comparison purposes, the manual calculation results were also compared with a heat pump simulation model by Greyvenstein.

For the non-azeotropic mixture the design procedure was also explained, whereby the Refprop Program was used for the calculation of pure and non-azeotropic refrigerant properties. The calculation results are given as diagrams depending on the refrigerant composition and are discussed using these diagrams. It is not discussed how by changing of the composition the adaption of the temperature profiles in the heat exchangers to the outer fluids change. Therefore, certain mismatches of temperature profiles can occur and could give cause to a deterioration of the energy efficiency. So, this theoretical evaluation of refrigerant mixtures shows only the behavior of the refrigerant cycle, but not the total system with the secondary fluids. This would be important especially in the case of refrigerant mixtures in order to save energy by matching the temperature profiles. Nevertheless, the various effects inside the cycle have been analysed and the changes of the thermodynamic conditions inside the cycle have been calculated. Further research work should be done to make use of the whole benefits of refrigerant mixtures in heat pumps when considering not only the inner cycle but also including into the analysis the temperature profiles of the secondary fluids.

Paper P372
The Effectiveness of a Ground-Coupled Heating and Cooling System

In this paper a designing and simulation program for reversible heat pumps is described. The program includes water-to-air and air-to-air systems.

All main components of the refrigeration cycle are simulated by the program. The compressor is described by curves which are supplied by the manufacturer. The heat exchangers are described by the first thermodynamic law and by equations for the heat transfer. The condenser is divided into three parts: superheating, condensing, and subcooling. The evaporator is divided into two parts: evaporating and superheating. For all parts there are used individual equations for the heat transfer.

With the program exists the possibility to simulate two kinds of heat exchangers: tube-in-tube heat exchangers for counter-flow configurations for refrigerant-to-water,

and plate fin-and-tube heat exchangers with plain fins for cross-flow configuration for refrigerant-to-air. The capillary tube is selected in dependency on the pressure drop between condenser and evaporator and the refrigerant mass flow rate. The data bases have been taken from the literature. The authors want to investigate with this program the effectiveness of an air-to-air heat pump and of a special water-to-air heat pump. This heat pump is connected on the water side with the municipality water supply.

For verification the authors compare the simulation results with experimental values and with calculated results from another program (HPSIM). The investigation is made for the cooling and the heating mode. The simulation program can simulate the air-to-air heat pump with only low deviations from the experimental values. For ground source heat pumps the deviation is clearly higher. The HPSIM program can simulate the experimental data, also: For air source the deviation is higher, for ground source the deviation is lower in comparison to the introduced simulation program.

For the comparison of air source heat pumps with ground source heat pumps it was found experimentally that ground source heat pumps have a clearly higher COP, 29% for heating mode and 39% for cooling mode. Further investigations are recommended by the authors for optimizing the possible performance and the first costs.