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Tehnologije toplotnih črpalk

Heat-Pumping Technologies

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Človeštvo ima v sedanjem času številne probleme: rast števila svetovnega prebivalstva, predvsem v deželah v razvoju, spremembe klime zaradi spuščanja CO_2 v ozračje z gorenjem fosilnih goriv in drugih plinov, ki povzročajo učinek tople grede, in tanjšanje ozonske plasti. Tehnologije toplotnih črpalk, to je hlajenje, klimatizacija in toplotne črpalke, ki so večinoma nepoznane in težko razpoznavne za široke množice, imajo možnost za zmanjševanje negativnih vplivov predstavljenih problemov. Izboljšati je treba znanje ljudi o teh sistemih. Te tehnologije so zanesljive, energijsko učinkovite, prijetne za okolje, v uporabi so kjerkoli po svetu in njihova industrija obrne le 10% manj denarja od avtomobilske industrije. Tehnologija toplotnih črpalk je tudi ključna tehnologija za dosego ciljev Kyotskega vrha.

(Ključne besede: črpalke toplotne, razvoj črpalk, hladiva, vplivi na okolje)

Mankind presently has serious problems, the growth of the world population primarily in the developing countries, the expected climate change due to polluting the atmosphere with CO_2 from burning fossil fuels and other greenhouse gases, and ozone depletion. Heat-pumping technologies, i.e. refrigeration, air conditioning, and heat pumps, more or less unknown and hardly recognised by the public, have the potential for reducing the negative effects resulting from these boundary conditions. But the public awareness of these technologies has to be improved. Heat-pumping technologies are reliable, energy efficient, and environmentally friendly, they are in use world wide and the turn-over of the related industry is only 10 % less than the turn-over of the automotive industry. Heat pumping is one of the key technologies required to achieve the targets set at the Kyoto summit.

(Keywords: heat pumps, pump development, refrigerants, environmental effects)

0 UVOD

Človeštvo ima v sedanjem trenutku tri glavne probleme, ki so medijsko zelo zanimivi: najbolj resen je tanjšanje ozonske plasti, ki povzroča kožnega raka in uničuje biosfero morja; naslednji je globalno ogrevanje ozračja, tretji pa je hitra rast človeškega prebivalstva. Resnica je, da moramo spremeniti vrstni red teh problemov. Rast števila prebivalstva je največji problem, sledi mu ogrevanje ozračja, ki je posledica vedno večje rabe energije.

Tehnologije toplotnih črpalk, tj. hlajenje, klimatizacija in toplotne črpalke, ne morejo rešiti problema naraščanja števila prebivalstva. Imajo pa možnost za zagotovitev zalog hrane s hlajenjem, zagotovitev ugodja in higienskih razmer s klimatizacijo in zmanjšanje rabe energije posredno z odpravljanjem kvarjenja hrane in neposredno z uporabo proste energije in odpadne toplote za zagotovitev uporabne toplote s toplotnimi črpalkami z dodajanjem eksergije prosti anergiji.

0 INTRODUCTION

Mankind has three major global problems. According to the media, the most serious problem is ozone depletion resulting in skin cancer and the destruction of the biosphere of the sea. The second problem relates to global warming and the expected climate change, and the third is the rapid growth of the world population. However, in reality we should change the order of these problems. The growth of the world population is the main problem, followed by global warming as a consequence of this growth and the increased energy consumption, which goes hand in hand with these changes.

Heat pumping, i.e. refrigeration, air conditioning and heat pump technologies, cannot solve the problem of the growth of the world population, but it has the potential for ensuring food supply by utilising refrigeration, providing comfort and hygienic conditions by supplying heating and cooling as well as humidification and dehumidification depending on the climatic conditions. Heat pumping can indirectly reduce the energy demand by avoiding the spoilage of food as well as directly by utilising free energy and waste heat to provide useful heat by means of heat pumps adding exergy to the collected anergy.

1 ZGODOVINA TEHNOLOGIJ TOPLOTNIH ČRPALK

Toplotne črpalke so stara tehnologija. Leta 1824 je Carnot odkril teoretične osnove toplotnih črpalk, tj. obrnitev naravnega toka toplote od višje temperature k nižji z dodajanjem visoko vredne energije; proces, ki je rezultat tega, se lahko uporablja tako za pridobivanje toplote kakor tudi hladu. Zanimivo je, da se je to zgodilo še preden sta bila oblikovana prvi in drugi zakon termodinamike.

Leta 1835 sta Perkins in Evans neodvisno drug od drugega razvila prvi parni kompresorski hladilnik, kar je bilo začetek uporabe mehanskih hladilnih tehnologij za hranjenje živil. Kmalu je sledila namestitev prve toplotne črpalke. Leta 1855 je Peter Ritter pl. Rittinger oblikoval, glede na zapiske Carnota, izvedel in preskusil prvi mehanski parni rekompresor (MVR) pri proizvodnji soli v Ebenseeju, zgornja Avstrija, kar je bila prva toplotna črpalka v obratovanju. Imela je tri centrifugalne kompresorje s celotno električno močjo 20 MW in hladilno število (HŠ) v obsegu od 12 do 16.

Razvoj toplotnih črpalk je šel naprej. Carre je iznašel absorpcijski krog z delovnim sredstvom amoniak/voda, Linde je znanstveno raziskoval parne kompresorske hladilnike in uvedel številna nova hladiva: npr. amoniak in CO_2 ter uvedel klimatizacijo. Willis Carrier, ki je bil zelo dejaven na tem področju, pa je postal oče te tehnologije; omogočil je možnost življenja v področjih z izrednimi klimatskimi razmerami.

Edini problem v teh časih so bila hladiva. Med najuspešnejšimi je bil amoniak, ki pa je strupen, neznosno smrdi in je pod določenimi pogoji gorljiv, SO_2, ki ga prav tako uporabljamo kot hladivo, je najbrž najbolj strupeno uporabljano hladivo, CO_2, ki je prevladoval do konca tridesetih let, je visokotlačen fluid, propan pa je eksploziven.

Tako se nihče ne more čuditi, da so CFC in HCFC, ki sta jih iznašla Midgely in Henne iz družbe Frigidaire, katero je kasneje kupil DuPont, začeli kot nestrupena in negorljiva »varna« hladiva vstopati in kasneje prevladovati na trgu. S temi hladivi je bila mogoča 30 barska tehnologija, predstavljena je bila hermetična oprema in s tem je tehnologija toplotnih črpalk, ki je bila do takrat na voljo samo za industrijsko uporabo, vstopila na novo področje, na področje hišnih naprav (pregl. 1). Na drugi strani je v velikih sistemih amoniak preživel, izginil pa je v alternativnih hladivinih procesih.

2 MONTREAL IN REZULTATI

Leta 1987 so tehnologije toplotnih črpalk prišle v obravnavo v Montrealskem protokolu

1 THE HISTORY OF HEAT PUMPING TECHNOLOGIES

Heat pumping is an old technology. In 1824 S. Carnot described the theoretical basis for heat pumping, i.e. reversing of the natural heat flux from a higher to a lower temperature by adding high-grade energy; the process resulting from these considerations is suitable for producing both heat and cold. The interesting thing is that this idea was put forward before the first and second laws of thermodynamics were formulated.

In 1835, Perkins and Evans independently developed the first vapour-compression refrigeration machines, which was the beginning of the use of mechanical refrigeration technologies for food preservation. The first heat-pump installation soon followed. In 1855, Peter Ritter von Rittinger designed, built and operated the first mechanical vapour recompression MVR system (based on the work of Carnot) in the salt production plant in Ebensee, Upper Austria. This was the first heat pump in operation. At present there are three centrifugals with a total electric input of 20 MW and coefficients of preformance (COP) in the range of 12 to 16 in operation at this site.

The development of heat-pumping technologies continued with Carré's invention of the absorption cycle with an ammonia-water working pair. Linde investigated vapour-compression refrigeration cycles, he introduced several new refrigerants like ammonia and CO_2. Air conditioning was introduced, and Willis Carrier, who was very active in this field, became the father of this technology. Air conditioning offered the possibility to live in regions with extreme climatic conditions.

The only problem at this time were the refrigerants, the successful ones being ammonia, which is toxic, smells horrible, and under certain circumstances is flammable, SO_2, also used as a refrigerant, is probably the most toxic natural substance available, CO_2, which dominated marine refrigeration and air conditioning applications until the end of the thirties, is a high pressure fluid, and propane is explosive.

With this background nobody should be surprised that the CFCs and HCFC's developed by Midgely and Henne of the Frigidaire company - which was later bought by DuPont – were promoted as non-toxic and non-flammable "safety" refrigerants and later came to dominate the market. Using these refrigerants a common 30-bar technology was possible, hermetic equipment introduced, and heat-pumping technologies, suitable at this time only for industrial applications, entered a new field, the field of household appliances (Table 1). Of the old refrigerants, only ammonia survived for use in large systems, alternative cycles disappeared.

2 MONTREAL AND THE RESULTS

In 1987, heat-pumping technologies came under discussion through the Montreal Protocol on Subglede snovi, ki tanjšajo ozonsko plast. Osnovne raziskave sta opravila Molina in Rowlands. Rezultati so bili napoved tanjšanja ozonske plasti, posledica tega pa naraščanje števila kožnega raka ter uničevanje biosfere. Pokazana je bila tudi slika, ki prikazuje tanjšanje ozonske plasti (TOP - ODP) in možnost svetovnega segrevanja (MSS - GWP) za različna hladiva (sl. 1). Zanimiv je bil vir te slike tj. DuPont.

Tanjšanje ozonske plasti je bolj ali manj rešeno s sporazumi v Londonu in Kopenhagnu, CFC so že prepovedani v industrijskih državah, HCFC pa, ki so manj škodljivi ozonu, morajo biti izločeni do leta 2035, v Evropski zvezi do leta 2015. Evropska komisija v zadnjem času pospešuje te procese, v nekaterih evropskih državah so že realizirani. Toda to velja samo za industrijske države. Države v razvoju imajo veliko daljši čas za spremembo tehnologij iz CFC na HCFC in končno na hladiva brez klora. Morda lahko pride do problema, da bodo te tehnologije dosežene ne da bi bili odpravljeni HCFC.

stances that deplete the Ozone Layer. The basis was an investigation carried out by Molina and Rowlands, the results were predictions on the depletion of the ozone layer which would result in an tremendous increase in the rates of skin-cancer and the destruction of the biosphere. They produced a nice graph showing the ozone depletion potential (ODP) and the global warming potential (GWP) of different working fluids (Fig. 1). Interestingly, the source of this graph was DuPont.

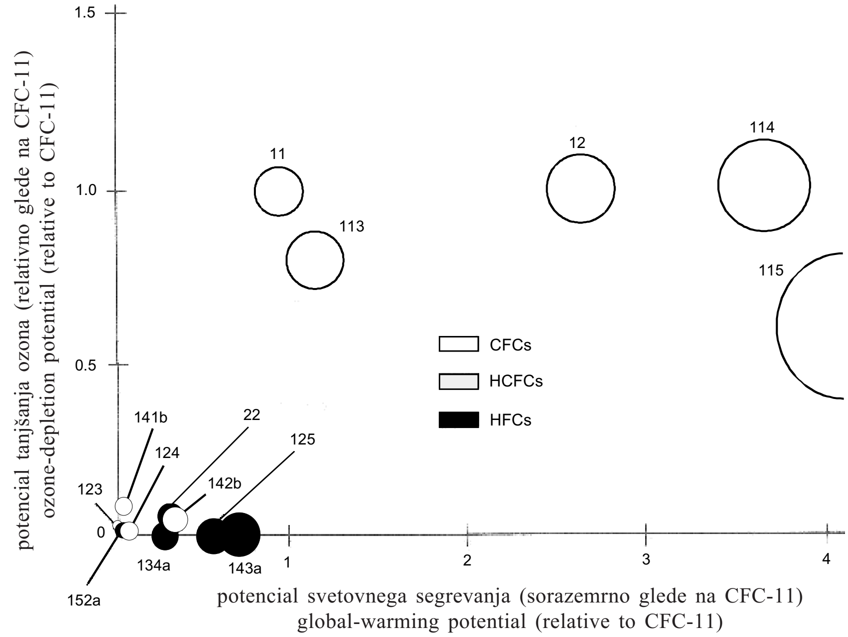
The problem of ozone depletion has been more or less solved by the follow-up agreements decided in London and in Kopenhagen with the result that CFCs are already forbidden in the industrialised countries and HCFCs, less harmful for the ozone layer, are to be phased out by 2035 or 2015 in the case of the European Union. And the Commission is currently considering an acceleration of this process, which has already been completed in some European countries. This situation is only valid for the industrialised countries; the developing countries have a much longer time frame in which to change their technologies from CFCs to HCFCs and finally to chlorine-free fluids. It might become a problem if they go this way and do not omit the HCFC step.

Preglednica 1. *Okoljski vpliv hladiv*
Table 1. *Environmental Impact of Refrigerants*

oznaka nomenclature		lokalni vplivi local effects		svetovni vplivi global effects				
		gorljivost (koncentracija v zraku) flammability (concentration in air) (%)	strupenost toxicity	doba trajanja v atmosferi atmospheric life time (a)	TOP - ODP (potencial tanjšanja ozona - ozon depletion potential) (R-11 = 1)	MSS - GWP (potencial globalnega segrevanja - global warming potential - kg CO_2 /kg) časovno obzorje time horizon (a)		
						20	100	500
CFC								
R-11	($CFCl_3$)	-	5a	60	1,0	4500	3500	1500
R-12	(CF_2Cl_2)	-	6	130	1,0	7100	7300	4500
R-113	($C_2F_3Cl_2$)	-	4-5	90	1,07	4500	4200	2100
R-114	($C_2F_4Cl_2$)	-	6	200	0,8	6000	6900	5500
R-115	(C_2F_5Cl)	-	6	400	0,52	5500	6900	7400
R-500	(R12+R152a)	-	5a	-	ca. 0,7	5400	5400	3400
R-502	(R22+R115)	-	5a	-	ca. 0,2	4800	4300	4000
HCFC:								
R-22	(CHF_2Cl)	-	5a	15	0,055	4100	1500	510
R-123	($C_2HF_3Cl_3$)	-	-	2	0,02	310	85	29
R-124	($CHClFCF_3$)	?	?	7	0,022	1500	430	150
R-141b	(CCl_2FCH_3)	7,4..15,1	?	8	0,11	1500	440	150
R-142b	($C_2H_3F_2Cl$)	6,9..14,9	-	19	0,065	3700	1600	540
HFC								
R-23	(CHF_3)	-	?	310	0	-	-	12
R-32	(CH_2F_2)	14,6	?	16	0	-	650	220
R-125	(C_2HF_5)	-	?	28	0	4700	2500	860
R-134a	($C_2H_2F_4$)	-	?	16	0	3200	1200	420
R-143a	(CF_3CH_3)	7,1	?	41	0	4500	2900	1000
R-152a	($C_2H_4F_2$)	3,7..17,1	-	2	0	510	140	47
ostalo / others								
R-50	(CH_4)	4,9..15,0	5b	10	0	63	21	9
R-270	(C_3H_6)	2,0..11,1	?	-	0	3	3	3
R-290	(C_3H_8)	2,1..9,5	5b	-	0	3	3	3
R-600	(C_4H_{10})	1,5..8,4	5	-	0	3	3	3
R-600a	(C_4H_{10})	1,8..8,4	5b	-	0	3	3	3
R-717	(NH_3)	15,0..25,0	2	-	0	-	-	-
R-718	(H_2O)	-	6	-	0	-	-	-
R-744	(CO_2)	-	5	120	0	1	1	1
R-764	(SO_2)	-	1	-	0	-	-	-

Poleg tanjšanja ozonske plasti obstaja še en vpliv CFC in HCFC. To je njihov prispevek h globalnemu segrevanju z naraščajočim sevanjem, ki ga poznamo kot učinek tople grede. Za osnovo je bil vzet R-11, ki je prav tako podlaga za tanjšanje ozonske plasti.

Besides ozone depletion there is another global effect of CFCs and HCFCs, it is their contribution to global warming by increasing the radiative forcing of the natural greenhouse effect. This was originally expressed on the basis R-11, which has also been taken as a basis for ozone depletion.



Sl. 1. *TOP nasproti MSS za različne CFC, HCFC in HFC*
Fig. 1. *ODP versus GWP of different CFCs, HCFCs and HFCs*

Medtem ko tanjšanja ozonske plasti ne moremo izraziti na drug način, pa lahko potencial svetovnega segrevanja temelji na CO_2, kar nam daje primerjavo z ostalimi procesi kot je gorenje fosilnih goriv. Če vzamemo CFC-je in HCFC-je, alternative HFC-jev brez klora, potem se MSS meri v tisoč kilogramih CO_2, kar pa postane relativno glede na emisije 0,2 kg/kWh_t v primeru plina, 0,3 kg/kWh_t v primeru olja in 0,4 kg/kWh_t v primeru premoga. Če upoštevamo vse energijske porabe lahko ugotovimo, da je glavni povzročitelj klimatskih sprememb CO_2, ki se sprošča pri gorenju fosilnih goriv.

While ozone depletion cannot be expressed in another way, the global warming potential can also be based on CO_2, and this provides a connection to other processes like burning fossil fuels. For CFCs, HCFCs and the chlorine-free alternatives to HFCs the GWP is counted in thousands of kg of CO_2, but this becomes relatively small when considering CO_2 emissions of 0.2 $kg/kWh_{thermal}$ in the case of gas, 0.3 $kg/kWh_{thermal}$ in the case of oil and 0.4 $kg/kWh_{thermal}$ in the case of coal. In terms of global energy use the main contribution to the expected climate change will come from CO_2 as a result of burning fossil fuels.

3 ALTERNATIVNA HLADIVA

3 ALTERNATIVE WORKING FLUIDS

Sintetična hladiva brez klora kot nadomestek CFC in HCFC proizvajajo v kemični industriji kot hidrofluorokarbonati – HFC – R134a, R-125, R-32 in R143a. Samo R134a se lahko uporablja kot nadomestek R-12, slabše v nizkotemperaturnem območju, boljše v visokotemperaturnem območju, do 84 EC temperature kondenzacije. R-32 in R-143a, obe izvrstni hladivi, sta vnetljivi, R-125 pa ima termodinamične lastnosti, ki onemogočajo, da ga uporabljamo kot čisto hladivo. Rezultat so zmesi, pri katerih R-134 in R-125 uporabljamo za zadušitev vnetljivosti. Takšne zmesi so R-404 in R-507 kot

The synthetic, chlorine-free alternatives to CFCs and HCFCs provided by the chemical industry are the hydrofluorocarbons HFCs R-134a, R-125, R-32 and R-143a. But only R-134a can be used as a pure fluid alternative to R-12, worse in the low-tempertaure region, better in the high-temperature region up to the 84 ^{o}C condensing temperature. R-32 and R-143a, both excellent refrigerants, are flammable, and R-125 has thermodynamic properties which make it unsuitable to be used as a pure refrigerant. The result are mixtures, where R-134a and R-125 are used to suppress flammability. Such mixtures are R-404A and R-507 as alternatives for R-502, R-407C as an alternadomestek za R-502 in R-407C kot nadomestek za R-22. Pravkar pa prihaja na trg R-410A, ki je zelo učinkovito hladivo in ustreza 40 barni tehnologiji.

Poleg tega da je večina teh nadomestkov neazeotropnih, imajo veliko zmožnost segrevanja ozračja, ker bo postalo naslednja tema razprav tehnologij toplotnih črpalk.

Naslednja možnost je vpeljava naravnih hladiv, npr. amoniak (R-717), ogljikovodiki propan (R-290), propilen (R-1270), ali izobutan (R-600a), voda (R-718) in CO_2 (R-744). Amoniak in ogljikovodiki ne zadostujejo zahtevam po varnih hladivih zaradi strupenosti in gorljivosti; voda in CO_2 pa sta varni hladivi [5].

Toda CFC niso mogli nadomestiti starega hladiva amoniaka (R-717) v celoti; v številnih hladilnih sistemih je bil amoniak vedno prva izbira, ker je odlično hladivo, je poceni v primerjavi s (H)CFC in je prijeten za okolje. Obstajajo seveda nekatere pomanjkljivosti: amoniak je strupen in njegov vonj, ki je zelo značilen, lahko povzroči paniko. Baker ne reagira z amoniakom in običajno se uporabljajo odprti kompresorji. Amoniak ima naraščajoč delež v novi opremi, razvoj gre naprej z namenom zmanjševanja deleža hladiva v sistemu.

Ogljikovodiki so dosegli najmanj en uspeh, izobutan ali zmesi propana in izobutana se uporabljajo kot hladiva v hladilnikih in zamrzovalnikih. Propan pa ima še eno odliko: je odlično nadomestilo za R-22, če pa uporabimo notranji prenosnik toplote, postane še bolj učinkovit kot R-22 z enako hladilno močjo [6]. Problem propana je omejevanje proizvajalcev kompresorjev, kaže, da je v ZDA nekaj izdelovalcev, ki hočejo preprečiti uporabo propana in propilena.

Voda se je in se zelo uspešno uporablja v sistemih MVR; dandanes se uporablja tudi pri hladilnikih, pri katerih je voda hladivo in nosilec toplote. Zaradi majhne prostorninske hladilne moči uporabljamo centrifugalne kompresorje, najnižja izvedena moč pa je 1 MW.

Zelo zanimivo hladivo je CO_2. Naravno hladilno sredstvo CO_2 (R-744), ki ga je uvedel Linde leta 1881, je postalo pomembno hladivo (sl. 2). Uporabljano je bilo do konca tridesetih let kot hladivo za hlajenje na ladjah in za klimatizacijo v stavbah, v obeh primerih torej, ko je potrebno »varno« hladivo. Težave povzročajo termodinamične lastnosti CO_2; kritične vrednosti so 31 °C in 74 bar. To se dogaja predvsem pri višjih temperaturah v območju kritičnih vrednostih, kjer se bistveno zmanjšata moč in izkoristek.

Za CO_2 obstajajo in bodo še obstajale v prihodnosti številne uporabe, ki so nadgradnja

native for R-22 and, just entering the market, R-410A. Although a very efficient working fluid, R-410A requires a 40-bar technology.

The majority of these alternatives are non-azeotropic mixtures, they also have a high global-warming potential, and this will become, after ozone depletion, the next topic of the discussion on the global impact of heat-pumping technologies.

Another possibility, however, is switching back to the old “natural” refrigerants like ammonia (R-717), the hydrocarbons like propane (R-290), propilene (R-1270) and isobutane (R-600a), water (R-718), or CO_2 (R-744). Ammonia and the hydrocarbons do not meet the requirements of a “safety” refrigerant because of toxicity and/or flammability, but water and CO_2 are safety refrigerants [5].

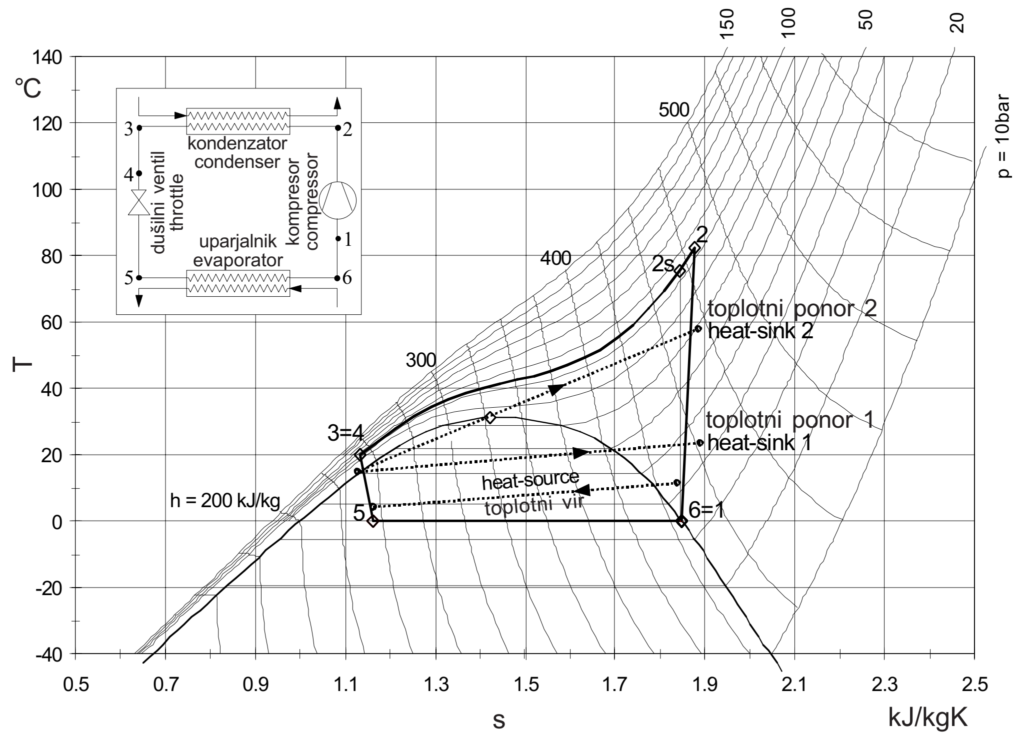
Not even CFCs have been able to completely replace the old refrigerant, ammonia (R-717). In large refrigeration systems ammonia has always been the first choice because it is an excellent refrigerant, it is cheap compared with the (H)CFCs, and it is environmentally benign. But there are some disadvantages: ammonia is toxic, and its characteristic smell, which acts as a warning signal, can cause panic. Copper is not compatible with ammonia, and open compressors are usually used. Nevertheless, ammonia has an increasing share in new equipment where developments are underway to reduce the refrigerant charge of the systems.

The hydrocarbons have achieved at least one success, isobutane or mixtures of propane and isobutane are used as refrigerants in refrigerators and freezers. But propane has another feature: it is an excellent substitute for R-22, and using an internal heat exchanger it becomes even more efficient than R-22 with about the same cooling capacity [6]. One problem associated with propane are the restrictions made by compressor manufacturers, and it seems that at least one large compressor manufacturer in the USA wants to prevent the use of propane and propilene.

Water has been and is being used successfully in MVR systems; but nowadays it is also used for chillers where water is both refrigerant and heat carrier. Due to the low volumetric cooling capacity centrifugals have to be used, and the smallest capacity presently realised is about 1 MW.

A very interetsing refrigerant is CO_2. The “natural” working fluid CO_2 (R-744), introduced by Linde in 1881 (Fig. 2), was used until the end of the thirties as a refrigerant for marine cooling and for air-conditioning systems in buildings, both applications where a “safety” refrigerant was required. Difficulties were caused by the thermodynamic properties of CO_2, the critical data are about 31^{O}C and 74 bar. This resulted in a trans-critical operation where both capacity and efficiency dropped significantly at high ambient temperatures.

For CO_2 there is an increasing number of applications which are superior to the present solutions with respect to the environment and also with



Sl. 2. *Diagram temperatura/entropija za CO_2 s pod- in z medkritičnim krogom*
Fig. 2. *Temperature/Entropy Diagram of CO_2 with a sub-critical and a trans-critical cycle*

sedanjih rešitev z vidika varovanja okolja in učinkovitosti [7]. Kot primer lahko navedemo spremembe v uparjalniškem sistemu hlajenja sekundarnega kroga za zmanjšanje polnjenja s hladivi, primeri ko se ne moremo izogniti izgubam hladiva in nove uporabe z višjimi učinkovitostmi, ki jih lahko dosežemo z uporabo tega hladiva.

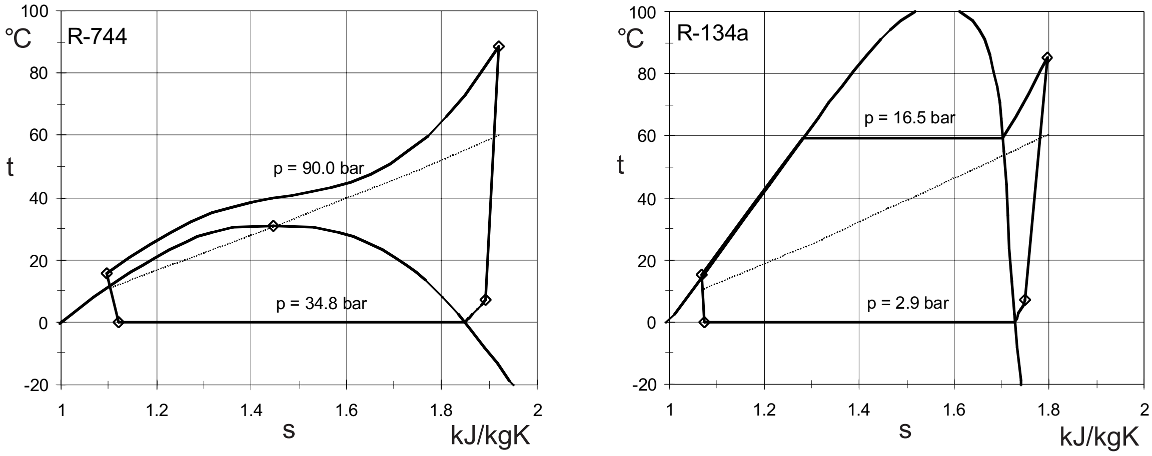
Uporabljamo ga tudi za priredbe toplotnih črpalk s temperaturami kondenzacije nad 30 °C, kar je predlagal prof. Lorentzen, s tlaki do 140 bar [8]. Ta krožni proces je označen z uparjanjem v podkritičnem področju in s kondenzacijo v nadkritičnem področju. Raziskujejo in testirajo se premične klimatizacijske naprave, posebno dvojen naprave imajo določene prednosti pred drugimi. Za pripravo tople vode (sl. 3), hladilnike zraka in rekuperatorje toplote [2], za sušilnike in razvlaževalnike je CO_2 v prednosti pred konvencionalnimi sistemi. Resnični problem CO_2 ni tehnologija, pač pa dostopnost komponent v velikih količinah po zmernih cenah. CO_2 ni in ne bo zdravilo, ki lahko reši probleme pri hlajenju, klimatizaciji in toplotnih črpalkah, toda za posebne primere je najboljša rešitev.

Izbirni kriteriji za hladiva morajo obsegati izkoristek, varnost in okoljsko sprejemljivost. Glavni problem je izkoristek, ker to pomeni energijsko porabo in le to moramo zmanjšati. Varnost je seveda zelo pomembna, toda problem varnosti lahko rešimo z uporabo ustrezne tehnologije. Dokaz "dodatne nevarnosti", ki se uporablja v novih sistemih, ni

respect to efficiency [7]. Examples are the change from direct evaporation systems in refrigeration to secondary loop systems for reducing the refrigerant charge, applications where refrigerant losses cannot be fully avoided, and new applications with higher efficiencies, which can be achieved by utilising CO_2 and the cycle characteristic.

For heat-pump applications with condensing temperatures exceeding 30 ^{O}C the transcritical cycle, also proposed by the late Prof. Lorentzen, with pressures up to 140 bar has to be used [8]. This cycle is characterised by evaporation taking place in the sub-critical region, whereas heat rejection occurs in the super-critical region. Mobile air conditioning is being investigated and tested in depth, stationary air conditioners, especially dual-mode systems, also show advantages. For once-through hot-water production (Fig. 3), air-heating and heat-recovery systems [2], drying as well as dehumidification processes, CO_2 is superior to the conventional processes. The real problem of CO_2 is not the technology, but the availability of components produced on a large scale for a reasonable price. CO_2 is not and will not be a cure-all which solves all the problems of refrigeration, air conditioning, and heat pumps, but for special applications it is an unbeatable solution.

Selection criteria for refrigerants have to cover efficiency, safety and environmental acceptability. The main point is efficiency, because efficiency means energy requirement, and energy requirement has to be minimized. Safety is of course important, but the problem of safety can be solved by using the appropriate technology, and the argument of the additional risk which is often used for new



Sl. 3. *Grelnik vode s toplotno črpalko 10 do 60°C* COP_{co2}*=4,6,* $COP_{R\text{-}134a}$*=4,0*
Fig. 3. *Heat Pump Water Heater 10 to 60°C* COP_{co2} *= 4.6,* $COP_{R\text{-}134a}$ *= 4.0*

pravilen, dokler sistem deluje v veliko višjem nevarnem nivoju.

4 VPLIV TEHNOLOGIJ TOPLOTNIH ČRPALK

Toplotne črpalke so preskušena in zanesljiva tehnologija. V primeru proizvodnje hladu za zmrzovanje, klimatizacijo, za medicinske in industrijske procese nimajo konkurence. Za proizvodnjo toplote morajo toplotne črpalke tekmovati z običajnimi proizvajalci toplote s sežiganjem goriv, največkrat fosilnih.

Toplotne črpalke so energijsko učinkovita in za okolje prijetna tehnologija [1]. Ponujajo možnost prestavitve energije okoliškega zraka, vode ali tal oziroma odpadne toplote na temperaturni nivo, ki ustreza ogrevanju zraka, za proizvodnjo tople vode in tudi za industrijske procese, in sicer tako, da dodajajo majhen del zelo vredne energije, imenovane eksergije, k prosti energiji. Primerjava toplote iz toplotnih črpalk z običajnimi postopki pokaže, da s toplotnimi črpalkami lahko porabo primarne energije zmanjšamo za polovico.

Tehnologija toplotnih črpalk je uporabna povsod po svetu. V tem trenutku deluje okoli 120 milijonov enot s toplotno močjo 800 TWh/a, ki zmanjšujejo emisijo CO_2 za 0,12 Gton/a. Potencial za zmanjšanje emisij CO_2 v stanovanjskem področju s 30% je okoli 6% celotnih emisij na svetu, ki znašajo 20 Gton/a. To je eden največjih možnosti za zmanjšanje CO_2. Zato so toplotne črpalke ena glavnih tehnologij za znižanje emisij CO_2, ki izhajajo iz gorenja fosilnih goriv in ustrezajo ciljem Kyotskega protokola [3].

Problem je v tem, da samo 5 odstotkov teh toplotnih črpalk deluje v Evropi in če se osredotočimo samo na naprave za ogrevanje, je število okoli 1,2 milijona enot. To pomeni, da je Evropa glede toplotnih črpalk dežela v razvoju, ker prezira prednosti te tehnologije.

systems is not correct as long as applications exist with a much higher endangering potential.

4 THE IMPACT OF HEAT PUMPING TECHNOLOGIES

Heat pumping is a proven and reliable technology. For producing cold for refrigeration, air conditioning, medical and industrial processes it has no competitor. For producing heat as heat pumps it has to compete with conventional heat produced by burning fuels, mostly fossil fuels.

Heat pumps are an energy-efficient and environmentally friendly technology [1]. They offer the possibility to shift free energy from outdoor air, water or ground and waste heat to a temperature level required for space heating, hot-water production, but also for industrial processes, adding small amounts of high-grade energy, today called exergy, to the free energy. Comparing heat delivery by heat pumps with conventional methods, i.e. burning fossil fuels, one can easily show that with heat pumps the primary energy consumption can be at least cut in half.

Heat pumping is a technology used world wide. Presently, about 120 million units with a thermal output of 800 TWh/a are in operation, reducing CO_2 emissions by 0.12 Gt/a. The potential for reducing CO_2 emissions with a market share of 30 % in the building sector is about 6 % of the total world-wide CO_2 emissions of 20 Gt/a. This is one of the largest CO_2-reduction potentials for a single technology. Consequently, heat pumps are one of the key technologies for reducing CO_2 emissions resulting from burning fossil fuels and meeting the Kyoto targets [3].

The problem is that only about 5 % of these heat pumps are running in Europe, and if one concentrates on heating-only devices, the number is only in the range of 1.2 Million units. This means that in terms of heat pumps, Europe is a developing country neglecting the advantages of this technology.

5 SKLEPI

Ključ za usklajeni razvoj v energetskem trženju je izogibati se uničevanja okolja. Že leta 1824 je Sadi Carnot odkril termodinamična pravila za tehnologije toplotnih črpalk in je s tem tudi spremenil prvi in drugi glavni zakon termodinamike, ki sta ju formulirala leta 1842 Robert Mayer in 1950 Clausius. Če zasledujemo pogovore o energiji danes, si lahko mislimo, da Carnot in Clausius nista nikoli obstajala.

Ali (H)CFC resnično tanjšajo ozonsko plast, je še vedno vprašanje. Posledice naraščanja koncentracije toplogrednih plinov, kakor sta CO_2 in CH_4 v atmosferi, so, posebej za daljše obdobje, dobro poznane iz knjig o Greenlandskem ledu: preskusi na ledu kažejo, da naraščanje koncentracije CO_2 povzroča zvišanje povprečne temperature na našem planetu in s tem klimatske spremembe. To pomeni, da moramo previdno uporabljati fosilna goriva in jih moramo izkoriščati učinkoviteje. Toplotne črpalke so ena od tehnologij za dosego tega cilja.

"Uspeh na trgu ni pojav, je rezultat raziskav, odličnih izdelkov, izšolanih inštalaterjev, pomoči ustanov in političnih ciljev"

Če ne pozabimo teh dejstev, če vlada sprejme pomen te tehnologije in če obstaja resnična potreba po zmanjšanju emisij CO_2, potem se bodo toplotne črpalke uveljavile tudi v Evropi in prispevale k boljši prihodnosti. Od časa je odvisno, ali bomo dosegli Kyotske cilje, širili znanje in povečevali zavest za toplotne črpalke kot energijsko učinkovito in okolju prijazno tehnologijo v Evropi. En cilj še ni bil dosežen: to je cilj prepričati politike.

5 CONCLUSIONS

The key to sustainable development and rational energy management is avoiding the destruction of our environment. In 1824 Sadi Carnot discovered the thermodynamic rules for the heat-pumping technologies and he more or less predefined the first and the second laws of thermodynamics which were formulated in 1842 by Robert Mayer and in 1850 by Clausius. Following the energy discussion of today one might suppose that Carnot and Clausius had never existed.

Whether (H)CFCs really deplete the ozone layer is still a question. The consequences of an increased concentration of greenhouse gases like CO_2 and CH_4 in the atmosphere are, at least over a longer time scale, well known from the history of Greenland Ice. Probes of this ice show that an increased CO_2 concentration results in a significant increase of the average temperature on our planet and therefore a climate change. This means that we have to use our fossil fuels carefully, we have to utilize them more efficiently. Heat pumps are one of the key technologies to achieve this goal.

"Success on the market is not a phenomenon, it is the result of research, excellent products, skilled installers, the support of the utilities and a political target"

If we do not forget these preconditions, if governments accept the importance of this technology, if there is a real need for the reduction of CO_2 emissions resulting from international agreements, heat pumps will also succeed in Europe and contribute to a better future. It is high time, considering the Kyoto targets, to spread the knowledge and increase the awareness of heat pumps as an energy-efficient and environmentally benign technology across Europe. However, one goal has not been achieved until now: the goal of convincing politicians.

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