© Strojniški vestnik 46(2000)8,564-572
ISSN 0039-2480
UDK 621.313.12:536.2:621.574.013
Strokovni članek (1.04)

© Journal of Mechanical Engineering 46(2000)8,564-572
ISSN 0039-2480
UDC 621.313.12:536.2:621.574.013
Speciality paper (1.04)

Možnosti za znižanje temperature toplotnega vira z absorpcijskimi hladilnimi napravami

The Possibilities of Reducing the Temperature of the Heat Source for Absorption Chillers

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Povečanje pomembnosti s simultano proizvodnjo elektrike sprožijo toplota in mraz stroge zahteve po uporabi absorpcijskih hladilnikov. Naprave bi morale biti manjše, imeti manjšo hladilno zmogljivost in uporabljati nizko temperaturno ogrevano vodo pri 90°C ali nižjo. Zaradi tega so potrebne spremembe v konstrukciji generatorja. Padajoči sloj omogoča generatorjem uporabo vroče vode pri nižjih temperaturah. Omenjen tip generatorjev se izogiba visokim hidrostatičnim tlakom, potrebuje nižje pregretje in zmanjšuje mešanje raztopin. Zaradi tega lahko uporabimo za približno 7°C nižjo temperaturo vroče vode za dosego enakih hladilnih zmogljivosti.

(Ključne besede: generatorji, sloj padajoči, litijev bromid, prenos toplote)

The increasing importance of the simultaneous production of electricity, heat and cold results in increasingly rigorous demands on absorption chillers. These devices should be smaller, having a low cooling capacity and they have to be able to use low-temperature heating water at 90°C or below. As a result, changes in generator construction are needed. Falling-film generators allow the use of hot water with lower temperatures. This type of generator avoids the need for high hydrostatic pressure, requires lower superheating and diminishes solution mixing. Consequently, we can use hot water at a temperature 7°C lower and reach the same cooling capacity.

(Keywords: generators, falling-film, lithium bromide, heat transfer)

0 UVOD

Sistemi za soproizvodnjo toplotne in električne energije (STEE - CHP) imajo visoke energijske izkoristke, v primeru kadar uporabimo vso pridobljeno toplotno in električno energijo. Temperaturni nivoji toplote so odvisni od izbrane naprave. Plinske turbine omogočajo proizvodnjo pare, medtem ko plinski dizelski motorji proizvajajo samo vročo vodo na temperaturnem nivoju pod 100°C, običajno 90°C. V primeru manjših izvedb (pod 1 MW električne moči), so v uporabi dizelski motorji. Njihova prednost je v prilagajanju obremenitvam in dobrem izkoristku v širokem območju obremenitev. Para iz plinske turbine se lahko uporabi v industrijske namene. Toploto dizelskih motorjev odvajamo z vodo, ki se lahko uporabi samo za ogrevanje. V obeh primerih se pojavi presežek toplote v poletnem obdobju. Toploto moramo odvesti v okolico, za kar potrebujemo dodatno energijo. Hkrati so v poletnem času pričakovane večje potrebe po hladu. Presežek toplote iz STEE lahko uporabimo v

0 INTRODUCTION

Systems for combined heat and power (CHP) have a high energy efficiency when they use all the heat and power produced. The temperature levels of the heat depend on the selected device. Gas turbines are able to produce steam, but gas diesel engines only produce hot water at temperatures below 100°C, usually about 90°C. When the facilities are small (under 1 MW of electrical power), diesel engines are the preferred choice. Their advantages are operating flexibility and good efficiency over a wide range of loads. The steam from gas turbines can be used in industrial applications. Waste heat from diesel engines is rejected with the water which can only be used for heating. In both cases there is a surplus of heat in summer time which has to be put into the environment with the use of additional energy. At the some time in summer a greater demand for cooling is expected. Excess heat from CHP systems should absorpcijskih hladilnikih za proizvodnjo hladu. Za pogon absorpcijskih hladilnikov najpogosteje ostane le nizkotemperaturna toplota.

Na področju absorpcijskih hladilnih naprav z majhno hladilno močjo, ki jih poganja nizkotemperaturna vroča voda, je trg sorazmerno majhen. Eden glavnih vzrokov je visoka cena, ki je povezana z majhnim povpraševanjem po absorpcijskih hladilnih naprav. Trg je bolje razvit v Aziji in še predvsem na Japonskem. Uvoz z daljnjega vzhoda je onemogočen zaradi stroškov prevoza in neusklajenosti s predpisi v ES, kar je pomembno predvsem za hladilne naprave z majhno hladilno močjo.

Na trgu obstajata dve vrsti absorpcijskih hladilnih naprav, ena temelji na krožnem procesu z enojnim učinkom in druga z dvojnim učinkom, obe pa kot delovni par uporabljata vodno raztopino litijevega bromida. Pri obeh vrstah lahko za pogon uporabljamo plin ali paro, medtem ko nizkotemperaturna vroča voda zadošča le za pogon naprav z enojnim učinkom. Hladilne naprave, ki delujejo z delovnim parom amoniak/voda, so manj primerne, zaradi manjših vrednosti hladilnega števila (HŠ - COP) v enakih razmerah.

1 VPLIV NA HŠ IN HLADILNO ZMOGLJIVOST

Krožni procesi z enojnim učinkom so najprimernejši za absorpcijske hladilne naprave, ki so gnane z nizkotemperaturno vročo vodo. Spremembe vstopne in izstopne temperature povzročijo spremembo delovne točke absorpcijske hladilne naprave. Spreminjanje delovne točke lahko ublažimo s spremembo nivojev in koncentracij v napravi. Če so spremembe prevelike, se spremeni mehanizem prenosa toplote in snovi. Teh sprememb ne moremo več kompenzirati.

Toploto za pogon dovajamo v generator absorpcijske hladilne naprave. Nizka temperatura dovedene tople vode zahteva nizek tlak v generatorju. Tlak je odvisen od koncentracije raztopine in temperature v kondenzatorju. Znižanje koncentracije zniža učinkovitost absorberja zato ne moremo doseči nizke temperature na izstopu. Nižjo temperaturo v kondenzatorju pa dosežemo z nižjo temperaturo hladilne vode.

Delovanje absorpcijskih hladilnih naprav ni odvisno samo od vstopne temperature vroče vode, ampak tudi od temperature na izstopu. Izbrali smo primer s temperaturo hlajene vode na vstopu 12°C in 7°C na izstopu ter vstopno temperaturo vroče vode 90°C. Slika 1 prikazuje vpliv izstopne temperature vroče vode in hladilne vode na hladilno moč naprave pri nespremenjenem volumskem pretoku. Komercialne absorpcijske hladilne naprave so bile konstruirane za pogon s paro in kasneje prilagojene za vročo vodo pod 100 °C (več cevi v generatorju in kondenzatorju).

be used in absorption chillers to produce cold. Only low-level hot water is usually available for these applications.

There is a relatively small market for absorption chillers with low cooling capacities driven by low-temperature hot water. One of the main reasons for the small market is the high price which is the result of the low sales of these chillers. The market is, however, more developed in Japan and SE Asia. Importation of these chillers from the far East is obstructed by transport costs and harmonization with EU regulations. This is especially important for low-capacity chillers.

Two types of absorption chiller exist on the market, one based on single and another on double-effect cycles, both using aqueous lithium-bromide solution as the working pair. Both types could be driven by steam or gas, but for low-temperature hot-water applications only the single-effect chillers are apropriate. Chillers with amonia-water as the working pair are less convenient because of the lower COP for the same conditions.

1 INFLUENCES ON COP AND COOLING CAPACITY

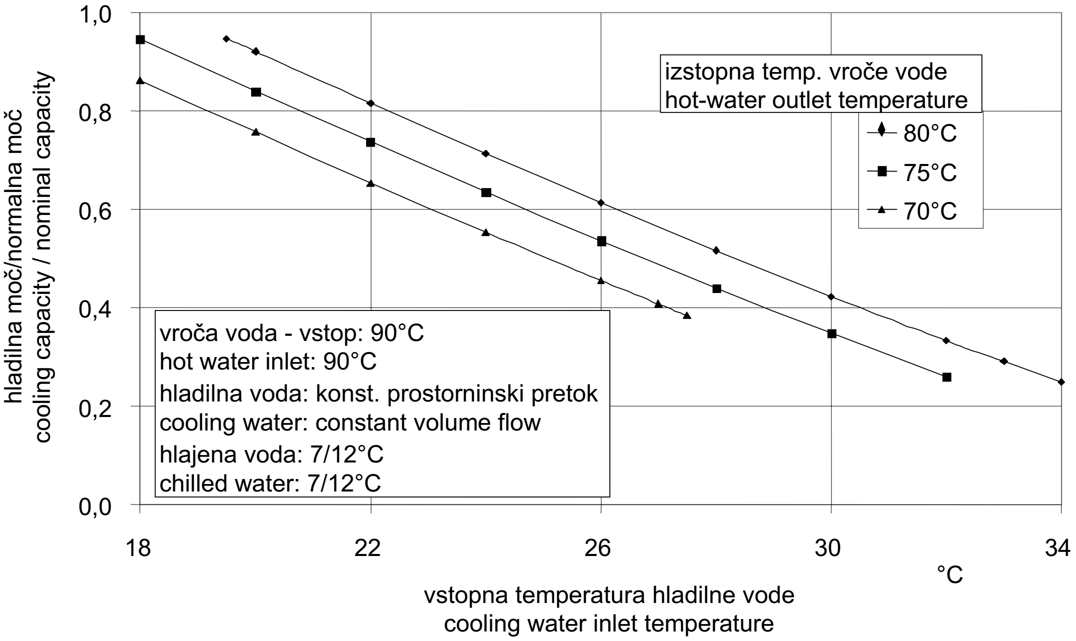
Single-effect chillers are the most suitable for absorption chillers driven by low- temperature hot water. Changes of any inlet or outlet temperature cause a different working point of the absorption chiller. Construction can compensate for these changes with different liquid levels and concentrations in the elements of the chiller. If the changes are too large, heat- and mass-transfer mechanisms can be changed too. These changes cannot be compensated any more.

Driving heat is put into the generator of the absorption chiller. A low hot-water input temperature requires a low pressure in the generator. Pressure depends on the concentration of the solution and the temperature in the condenser. The decrease in concentration reduces the absorber efficiency and the outlet chilled-water temperature cannot be reached. A lower temperature in the condenser is reached with a lower temperature of the cooling water. But both possibilities are limited.

The operation of absorption chillers depends not only on the inlet temperature of the hot water but also on its outlet temperature. We have selected an example with the temperature of chilled water at 12°C for the inlet and 7°C for the outlet and inlet hot-water temperature of 90°C. Figure 1 shows the influence of different outlet temperatures of hot water and inlet cooling-water temperature with a constant volume flow on the cooling capacity. It is a commercial absorption chiller designed to be driven by steam and adapted for hot water under 100°C (more tubes in the generator and condenser).

Znižanje temperature vroče vode do 80°C ne povzroči izrazitega zmanjšanja vrednosti HŠ, kar pa ne velja za hladilno moč. Moč je odvisna tudi od hladilne vode (sl. 1). V izbranem območju pričakovanih parametrov je zmanjšanje hladilne moči premosorazmerno z izstopno temperaturo vroče vode in temperaturo hladilne vode. Znižanje izstopne temperature za 5°C ima za posledico zmanjšanje hladilne moči za 8 %. Izstopne temperature pod 70°C so manj primerne zaradi velikih notranjih izgub v generatorju in premajhnem pregretju. To povzroča nepravilno delovanje hladilne naprave [1].

By reducing the temperature of hot water to about 80°C the COP does not decrease drastically, however the cooling capacity is significantly decreased. The capacity depends on the cooling water too (Figure 1). In the selected range of anticipated parameters a decrease of the cooling capacity is linearly proportional to the hot-water outlet temperature and the cooling-water temperature. A reduction of the outlet temperature by 5°C results in a decrease in the cooling capacity by 8%. Outlet temperatures below 70°C are unfavorable because of high internal losses in the generator and too low superheating. This causes incorrect chiller operation [1].



Sl. 1. *Vpliv zmanjšanja temperature hladilne vode na hladilno moč [1]*
Fig. 1. *Influence of cooling water temperature decrease on cooling capacity [1]*

Na trgu dostopne absorpcijske hladilne naprave so bile konstruirane tako, da jih poganja para ali vroča voda nad 100°C, ločitev hladiva in absorpcijskega sredstva je z vrenjem vodne raztopine litijevega bromida v posodi. Omenjeni način vrenja potrebuje visoko pregretje zlasti, kadar uporabljamo vodne raztopine soli. Za dosego toplotnega toka 50 kW/m^2 je potrebno pregretje za 12 °C [2]. Pri tem toplotnem toku je v generatorju konvektivno mehurčkasto vrenje. Manjši toplotni tok močno poveča površino generatorja in ceno hladilne naprave. Za dosego 50 kW/m^2 v generatorju z gladkimi cevmi (baker-nikel), je potrebna 18°C temperaturna razlika med grelno vodo in raztopino.

Existing commercial absorption chillers were designed to be driven by steam or hot water over 100°C and the separation is carried out by pool boiling of aqueous lithium-bromide solution. This type of boiling needs high superheating, especially when using aqueous salt solutions. To reach a heat flux of 50 kW/m^2 more than 12°C of superheating is needed [2]. At this heat flux, free convectional pool boiling occurs. A lower heat flux would strongly increase the surface of the generator and the price of the chiller. To reach 50 kW/m^2 in a generator with smooth copper-nickel tubes a temperature difference between the hot water and the solution of about 18°C is needed.

2 TEHNIČNE MOŽNOSTI

Nizkotemperaturno ogrevno vodo lahko uporabimo brez sprememb temperature hlajene in

2 TECHNICAL POSSIBILITIES

We can use low-temperature heating water, without changing the cooling and chilled water hladilne vode, če v generatorju: povečamo površino cevi (i), povečamo koeficient toplotne prestopnosti (ii) in zmanjšamo hidrostatični tlak (iii). Spremembe delovnega para ne bomo obravnavali.

Prva možnost (i) je najpogosteje uporabljena rešitev. Cilj lahko dosežemo z večjim številom cevi ali/in z uporabo orebrenih, ožlebljenih ali posebno obdelanih cevi. Če uporabimo več cevi, se močno povečata velikost hladilne naprave in cena. Prav tako se poveča količina raztopine v napravi in hidrostatični tlak. Z uporabo cevi z večjo površino se poveča samo cena.

Koeficient toplotne prestopnosti (ii) je mogoče povečati na strani vode in/ali na strani raztopine. Uporaba nizko temperaturne vroče vode omogoča nizek tlak v ceveh. Zaradi tega lahko uporabimo bakrene cevi, ki imajo trikrat boljšo toplotno prevodnost, kot običajno uporabljene Cu-Ni cevi. Z zmanjšanjem debeline stene cevi in spremembo materiala ne vplivamo bistveno (do 3 %) na koeficient toplotne prestopnosti. Pri nizko temperaturnem viru toplote lahko uporaba cevi z povečano ali izboljšano površino poviša koeficent toplotne prestopnosti na strani raztopine. Koeficient toplotne prestopnosti je močno odvisen od pregretja. Kadar v generatorju uporabljamo vrenje v sloju, je koeficient toplotne prestopnosti odvisen tudi od gostote masnega toka. Povečanje gostote masnega toka do 0,15 kg/s·m ima za posledico povečanja koeficenta toplotne prestopnosti. Z uporabo orebrenih in ožlebljenih cevi je koeficient prenosa toplote skoraj dvakrat večji [3]. Oba načina povečane površine omogočata boljšo razlitje kapljevine in s tem zmanjšanje suhih površin, ki zmanjšajo povprečni koeficient toplotne prestopnosti. Celotni koeficient toplotne prestopnosti je odvisen tudi od lete na vodni strani. Omejitve hitrosti na strani vroče vode so povezane z dopustnim tlačnim padcem. Pri nizkih hitrostih vroče vode je primerna uporaba cevi s povečano površino na notranji strani.

Slika 2 prikazuje vpliv na koeficient toplotne prestopnosti. Izbrali smo hitrost vroče vode med 0,5 in 2 m/s v cevi z notranjim premerom 18,5 mm. Majhen premer in relativno velike hitrosti omogočajo dober koeficient toplotne prestopnosti med vročo vodo in cevjo. Možna je tudi uporaba večjih hitrosti, kar daje celo boljše rezultate, pri čemer pa se močno poveča tlačni padec. Na strani raztopine je koeficient toplotne prestopnosti manjši.Koeficient toplotne prestopnosti je pri vrenju vodne raztopine LiBr slabši kot pri vrenju čiste vode. Pri vrenju v posodi dosežemo vrednost 5000 W/m^{2}K pri pregretju 20°C. Vrenje raztopine v padajočem sloju na gladke vodoravne cevi da slabše eksperimentalne rezultate [3]. To je v nasprotju z vodo, pri kateri opazimo povečanje koeficineta toplotne prestopnosti pri nizkih toplotnih tokovih tako na gladkih kot na povečanih površinah cevi [6].

Vrednost koeficienta toplotne prestopnosti 2500 W/m^{2}K dosežemo pri vrenju v posodi pri

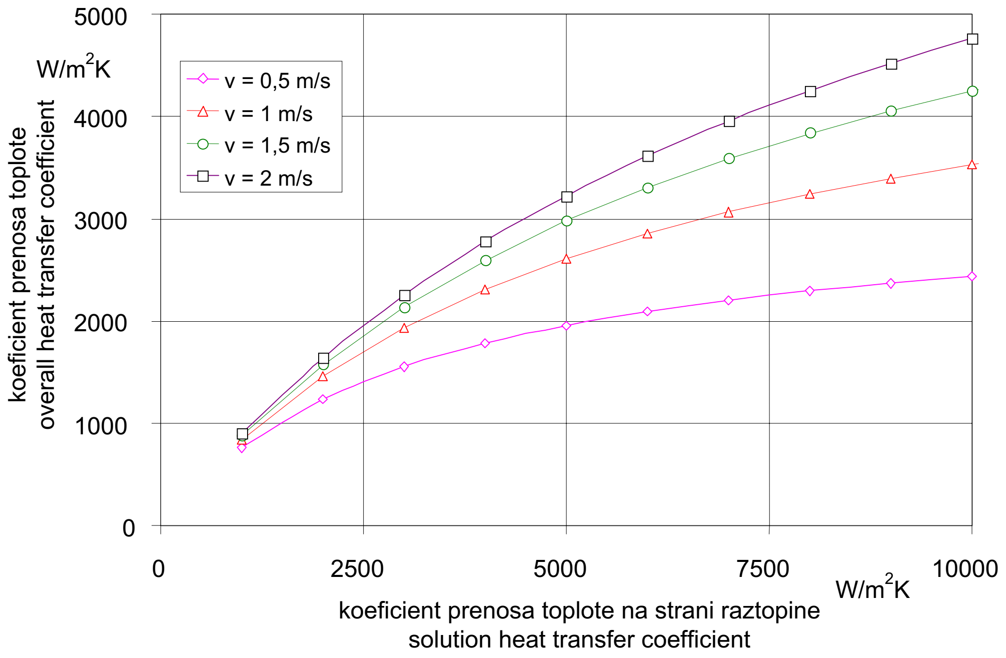
temperature, with the following changes to the generator: increasing the tube surface (i), increasing the heat-transfer coefficient (ii) and decreasing the hydrostatic pressure (iii). Changing the working pair will not be discussed.

The first possibility (i) is the most common solution. We can reach this goal with more tubes or/and using finned, grooved or specially treated tubes. If we use more tubes the chiller size and price will increase significantly. It will also cause an increase of the depth of the solution in a vessel and hydrostatic pressure. In case of non smooth tubes, only the price will be higher.

The heat-transfer coefficient (ii) could be increased on thewater side and/or the solution side. Using a low hot-water temperature enables a lower pressure in the tubes. As a consequence we can use Cu tubes with three times better conductivity rather than Cu-Ni tubes which are used in normal situations. The tube-wall thickness decreases and the material changes do not influence significantly (up to 3%) the overall heat-transfer coefficient. With a low-temperature heat source the use of extended or enhanced surfaces can increase the boiling heat-transfer coefficient of the solution. The heat-transfer coefficient depends strongly on superheating. When using thin-film boiling in a generator, the heat-transfer coefficient also depends on the mass-flow density. The increase of mass-flow density up to 0.15 kg/s·m increases the heat-transfer coefficient. Using finned or grooved tubes the heat transfer coefficient is almost twice a high [3]. Both types of extended surface enable a better spread of liquid and avoid dry surfaces which decrease the average heat-transfer coefficient. The overall heat-transfer coefficient also depends on the water side. The limits on the hot-water side are due to the water velocity being restricted by the maximum pressure drop. By using a low hot-water velocity, extended surfaces inside the tube are also a possibility.

Figure 2 shows the influence on the overall heat-transfer coefficient. Hot-water velocities between 0.5 and 2 m/s in a tube with a 18.5 mm inner diameter are selected. A small diameter and a relatively high velocity enables good heat-transfer coefficient between the hot water and the tube. The use of a higher velocity is also possible and gives even better results, but the pressure drop increases significantly. On the other hand, heat transfer on the solution side is low. In comparison with water the lithium-bromide boiling heat-transfer coefficient is weak. Using pool boiling, 5000 W/m^{2}K can be reached for only 20°C of superheating. Solution boiling in a falling film on smooth horizontal tubes gives poorer experimental results [3]. This is in contrast to water, where a significant increase in the low-heat flux is measured on smooth and structured surfaces [6].

The overall heat-transfer coefficient of 2500 W/m^{2}K by pool boiling at a temperature difference of 20°C and a hot-water velocity of 1.5 m/s can be



Sl. 2. *Vpliv koeficienta prenosa toplote na strani raztopine na celotni prenos toplote pri različnih hitrostih v ceveh*

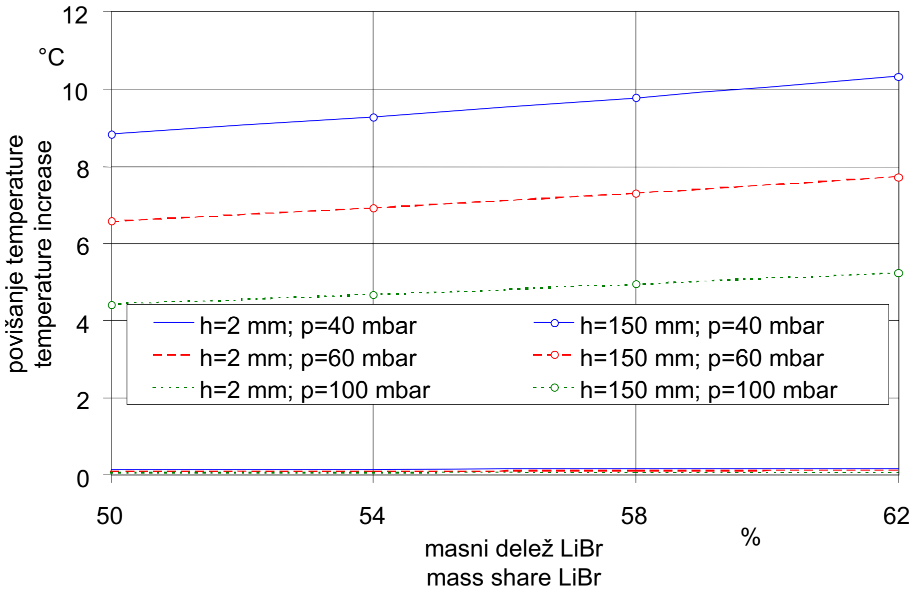
Fig. 2. *Influence of the solution heat-transfer coefficient on the solution side on the overall heat transfer with a different velocity in the tubes*

temperaturni razliki 20°C in hitrosti vroče vode 1,5 m/s. Podvojitev hitrosti vroče vode zmanjša potrebno temperaturno razliko za 2,5 °C ali zmanjša površino cevi za 20%.

Tlak (iii) v generatorju je odvisen od koncentracije raztopine in temperature kondenzacije. Vrenje je lahko v posodi ali v sloju. Cevi pri vrenju v posodi so potopljene v raztopini. Pri generatorjih s

reached. Doubling the hot-water velocity decreases the required temperature difference by 2.5°C or decreases the tubes' surface area by 20%.

Pressure (iii) in the generator depends on the solution concentration and the condensation temperature. We can use pool boiling or thin-film boiling in the generator. Tubes for pool boiling are immersed in the solution and boiling occurs on the tubes. With



Sl. 3. *Učinek hidrostatičnega tlaka na povišanje temperature*

Fig. 3. *Effect of hydrostatic pressure on temperature increase*

pršenjem se na ceveh oblikuje sloj raztopine. Nad snopom cevi je cev, ki razprši raztopino. Uporaba vrenja v sloju zahteva vodoravno postavitev naprave in s tem tudi cevi.

Absolutni tlak v generatorju je nizek (~ 70 mbar), zato ima hidrostatični tlak močan vpliv. V tankem sloju je povečanje temperature vrenja zaradi hidrostatičnega tlaka zanemarljiv. Pri vrenju v posodi pa je 150 mm pod nivojem raztopine je tlak približno 25 mbar višji in zaradi tega se poviša temperatura vrenja. Povišanje temperature vrenja v tankem sloju (2 mm) na cevi in cev, ki je 150 mm pod nivojem raztopine, je prikazana na sliki 3.

Hidrostatični tlak ima pri zelo nizkem tlaku v generatorju (40 mbar) in temperaturi v kondenzatorju (29°C) velik vpliv. Uporaba hladilne vode s temperaturo 31°C omogoča, da doseže temperaturo v kondezatorju okoli 36°C in absolutni tlak 60 mbar. S prehodom iz vrenja v posodi na vrenje v sloju lahko znižamo temperaturo vroče vode za 6,5 do 7,7 °C. Potrebna temperatura vroče vode se zniža zaradi znižanja hidrostatičnega tlaka. Absolutni tlak 100 mbar je neprimeren za generatorje z nizko temperaturo vroče vode, saj je ravnotežna temperatura približno 90°C (pri 58 mas. %) brez upoštevanja temperaturne razlike za prenos toplote in vrenja. Pri generatorjih gretih z nizko temperaturno vročo vodo je pri enakih pogojih vrenje v sloju kapljevine učinkovitejše od vrenja v posodi.

Padajoči sloj kapljevine v generatorju onemogoča mešanje raztopine. Zaradi tega imamo določeno porazdelitev temperature in koncentracij. Ravnotežna temperatura se močno poviša pri ceveh v spodnjem delu generatorja. Zaradi omenjenega razloga je priporočljivo večje število prehodov vroče vode skozi snop cevi. Vroča voda vstopa na spodnjem delu snopa cevi in raztopini z že zvišano temperaturo omogoča vrenje. V zgornjem delu generatorja je ogrevana voda že nekoliko ohlajena, pri čemer pa ima tudi raztopina nižjo koncentracijo. To omogoča največjo temperaturno razliko med vstopom in iztopom vroče vode ter zmanšanja eksergijskih izgub.

Na ceveh nastala para teč skozi snop cevi v kondenzator. Naloga generatorja je tudi onemogočiti vstop raztopine v kondenzator v primeru nepravilnega delovanja. Zato je kondenzator nameščen nad generatorjem. Hitrost pare je velika, ker je specifični volumen velik. Omejitve so pri tlačnem padcu in odnašanju sloja ali kapljic raztopine. Nespremenljivo hitrost in tlačni padec lahko dosežemo s povečanjem razmakov med cevmi.

Slika 4 prikazuje spremembo temperature in koncentracije na ceveh. Za zmanjšanje prostornine generatorja izberemo izmenično razvrstitev cevi. Prenosniki toplote s fazno spremembo imajo spremenljiv masni in volumski pretok kapljevine in pare. Zaradi tega se pogosto

falling-film generators the layer of the solution is produced by spraying it on the tubes. They require an additional tube, or tubes, for solution distribution above the tube bundle. Additional attention should be paid to setting up the device horizontally, because not only the absorber and evaporator but also the generator is of the falling-film type.

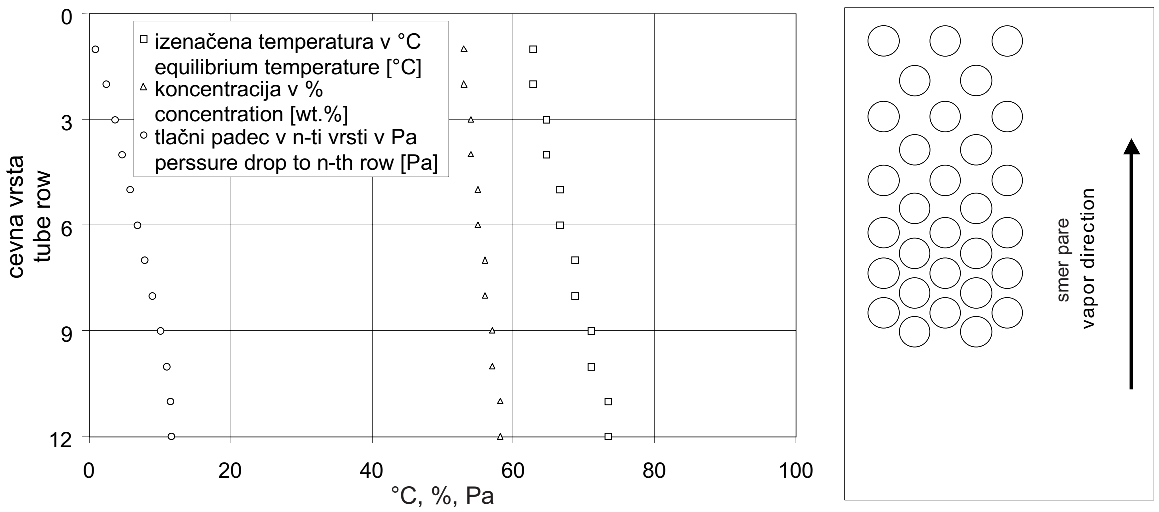
Since the absolute pressure in the generator is very low (~70 mbar) the hydrostatic pressure has a strong influence. There is a negligible boiling temperature increase in the thin film because of the hydrostatic pressure. But 150 mm under the solution level the pressure is about 25 mbar higher and consequently the boiling temperature increases. The boiling temperature increases in the case of a thin film (2 mm) on the tube, and the tube which is 150 mm under the solution level can be seen in Figure 3.

At a very low pressure (40 mbar) and temperature in the condenser (29°C) the hydrostatic pressure has the greatest influence. The use of cooling water at 31°C causes an internal temperature in the condenser of about 36°C and an absolute pressure of 60 mbar. The decrease in the required hot-water temperature by changing from boiling on immersed tubes to boiling in a falling film is between 6.5 and 7.7°C. This is a realistic hot-water temperature decrease with a reduced hydrostatic pressure. An absolute pressure of 100 mbar is not appropriate for low-temperature hot-water applications because the equilibrium temperature is about 90°C (at 58 wt.%) without any consideration of the temperature difference for heat transfer and boiling. For a low-temperature hot-water generator, thin-film boiling is much more efficient than pool boiling.

Falling-film generators also prevent mixing of the containing solution. Therefore, we have a clear concentration and temperature distribution. The equilibrium temperature for tubes with a lower position increases strongly. For this reason, more passes of the hot water through the tube bundle is recommended. The hottest water should inlet at the lower part of the tube bundle and meet with the hottest solution. On the top part, cooled hot water hits the solution with the lowest concentration. This enables the biggest temperature difference between hot-water inlet and outlet and decreases the exergy losses.

Vapor generated on the tubes goes through the bundle in the condenser. This is usually above the generator to prevent entry of the solution to the condenser in the case of faulty operation. Vapor velocities should be high because the specific volume is also high. The limitations are pressure drop and the solution-film or droplets carry off. A constant velocity and pressure drop can be maintained with an increased distance between the tubes.

Figure 4 presents thetemperature and concentration changes on the tubes. To reduce the volume of the generator an alternating tube arrangement is usually selected. Heat exchangers with a phase change have changeable mass and volume-

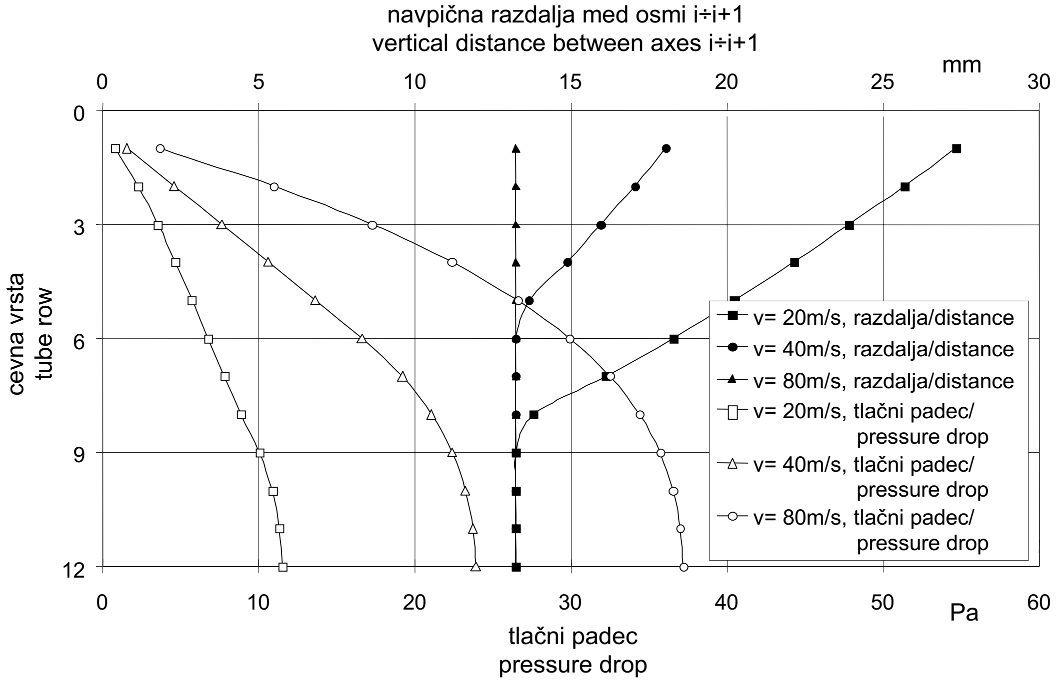


Sl. 4. *Ravnotežna temperatura na površini raztopine, povprečna temperatura in celotni tlačni padec do n-te vrste cevi (levo) in cevni porazdeljenosti (desno)*

Fig. 4. *Equilibrium surface temperature, average concentration and total pressure drop to the n-th tube row (left) and tube distribution (right)*

uporablja spremenljiva razdalja med cevmi. Pri izračunu smo zanemarili mešanje raztopine in konstanten toplotni tok na vseh ceveh (70 kW/m^2). Navpične razdalje med cevmi so izbrane z uporabo nespremenljive hitrosti pare (20m/s), med stolpci je vseskozi enaka razdalja, ki znaša 35 mm. Tlačni padec je majhen, njegovo linearnost pa dosežemo z nespremenljivo hitrostjo. Povečanjem hitrosti pare na 100 m/s povzroči tlačni padec 140 Pa [4]. Koncentracijsko razlika 5% je dosežemo pri gostoti masnega toka 0,1 kg/(s·m).

flow of liquid and vapor so varying spaces between tubes are often used. No solution mixing and constant heat flux on all tubes (70 kW/m^2) have been assumed. Vertical distances between tubes are selected on the basis of constant vapor velocity (20 m/s) and horizontal distances are fixed at 35 mm. No significant pressure drop can be seen and linearity is reached because the velocity is constant. The increase in velocity to 100 m/s causes a pressure drop to 140 Pa [4]. A concentration difference of 5% is reached with a mass flux density of 0.1 kg/(s·m).



Sl. 5. *Tlačni padec in navpična razdalja med cevnimi vrstami z različnimi največjimi hitrostmi*

Fig. 5. *Pressure drop and vertical distances between tube rows with different maximum velocities*

Najmanjša razdalja med cevmi je 6,5 mm [5]. To omogoča izdelavo z uvaljanjem cevi in mehansko čiščenje. Tlačni padec v cevnem snopu je majhen. Slika 5 prikazuje navpično razdaljo med cevnimi vrstami. Ko pri nespremenljivi vodoravni (40 mm) razdalji med osmi cevi omogočimo povečanje hitrosti, se bo navpična razdalja zmanjšala. Pri izbrani največji dovoljeni hitrosti (80 m/s) je razdalja nespremenljiva in omejena z najmanjšo razdaljo med cevmi. Gradient tlačne razlike se zmanjša zaradi manjše hitrosti. Izbrana srednja hitrost (40 m/s) zahteva večjo navpično razdaljo med cevmi v zgornjem delu prenosnika. Omenjeni učinek je še značilnejši pri nižji hitrosti (20 m/s), pri kateri samo zadnje tri cevi dosežejo najmanjšo razdaljo (omejena z najmanjšo razdaljo med cevmi). Tlačni padec med cevmi je nespremenljiv, dokler je razdalja določena s hitrostjo. V teh razmerah padec tlaka povzroči povišanje temperature za približno 0,1°C (pri 60 mbar in 55 %). Hitrost in tlačni padec padata, ko je omejitev razdalja med cevmi. Z večjo hitrostjo je mogoče zmanjšati višino cevnega snopa iz 240 mm (20 m/s) na 180 mm (80 m/s). Najmanjša razdalja med cevnimi vrstami v generatorju je določena s tehnologijo izdelave generatorja. Velika hitrost pare ne povzroči izrazitejšega tlačnega padca in povišanja temperature. Zaradi tega je primerno zmanjšati izmere generatorja.

3 SKLEP

Večina absorpcijskih hladilnih naprav uporablja v generatorju vrenje v posodi. Njihova konstrukcija je robustna. Pri vrenju v posodi je potrebna visoka vstopna temperatura grelne vode, ki omogoča pregretje in tudi mešanje raztopine. Znižanje vstopne in/ali izstopne temperature bistveno ne poslabša HŠ, ampak povzroči padec hladilne moči v absorpcijskih hladilnih napravah.

Pomemben napredek pri uporabi nizkotemperaturne tople vode so dosegli, s spremembo načina vrenja v generatorju - prehod iz vrenja v posodi na vrenje v sloju. Zaradi znižanja hidrostatičnega tlaka lahko uporabimo za približno 7 °C hladnejšo grelno vodo. Pri nižjem tlaku (nižji temperaturi hladilne vode) je vpliv še mnogo večji. Učinek vrenja v sloju je večji, če je več prehodov vroče vode, vstop vroče vode pa je na spodnjem delu generatorja. Dodatno povečanje lahko dosežemo z večjo hitrostjo vroče vode, rezultat tega je višji tlačni padec na strani vroče vode. S povečanjem hitrosti vroče vode iz 1,5 na 3 m/s lahko znižamo njeno temperaturo za 2,5°C. Z uporabo razširjene površine (orebrene ali ožlebljene cevi) se poveča koeficient toplotne prestopnosti raztopine skoraj za 100 %. Zmanjšanje debeline stene cevi in sprememba materiala nimata izrazitega vpliva (do 3 %) na koeficient toplotne prestopnosti. Generirana vodna para ima majhen vpliv na tlak v generatorju. Povišanje temperature zaradi padca tlaka je najvišje na spodnjih ceveh in pri hitrosti pare 80 m/s znaša samo 0,1°C.

The minimum gap between tubes is set to 6.5 mm [5]. This enables tube end attachment with roller expansion and mechanical cleaning. The pressure drop in the tube bundle shell be low. Figure 5 shows the vertical distances between tube rows. When at a constant (40 mm) horizontal distance, the allowed velocity is increased the vertical distance will be decreased. At the highest selected velocity (80 m/s) the distance is constant and limited with a minimum gap. The gradient of pressure difference decreases because of the lower velocities. A medium velocity (40 m/s) requires a higher vertical distance between the tubes in the upper half of the exchanger. This effect is more significant at the lowest velocity (20 m/s) where only the last three tubes reach the minimum distance (limited with a minimum gap). The pressure drop between tubes (one above another) is constant as long as the distance is defined by velocity. Under these conditions pressure drop causes a temperature increase of about 0.1°C (at 60 mbar and 55 wt.%). When the gap is at the limit, the velocity and pressure drop decrease. With a higher velocity the height of the tube bundle can be reduced from 240 mm (20 m/s) to 180 mm (80 m/s). With a small number of tube rows in the generator the distance between them is defined by production technology. High vapor velocities have not caused a significant pressure drop and temperature increase. As a result, it is reasonable to decrease the dimensions of the generator.

3 CONCLUSION

Most absorption chillers use pool boiling of the solution in a generator. Their construction is robust. On the other hand, a high temperature of the input heat is required not only for superheating but also for mixing of the solution. Lowering input and/or output temperatures does not make the COP significantly worse but causes a reduction in the cooling capacity of the absorption chillers.

Using low-temperature hot water the greatest improvement is achieved when changing from a pool-boiling generator to a falling-film generator. About 7°C cooler driving water can be used and the hydrostatic pressure is reduced. At low pressure (low cooling-water temperature) the influence is even stronger. The effect is greater with more passes of hot water with the inlet at the bottom of the tube rows of the generator. Improvements can be obtained with higher hot-water velocity but the result is a higher pressure drop too. We can reduce the hot-water temperature by 2.5°C if we increase its velocity from 1.5 to 3 m/s. Using extended surfaces (finned or grooved tubes) the solution heat-transfer coefficent is increased by almost 100%. The tube-wall thickness decreases and material changes do not significantly influence (up to 3%) the overall heat-transfer coefficient. The pressure drop of the generated steam through the tube bundle has a negligible effect. It causes a temperature of increase for only 0.1°C on the lower tubes by using vapor velocities of about 80 m/s.

Generatorji z vrenjem v posodi niso primerni za pogon z nizkotemperaturno toplo vodo. V takšnih primerih uporabljamo vrenje v sloju, kar omogoča optimalno konstrukcijo in razmeroma nizke proizvodne stroške.

We can conclude that generators with pool boiling are not convenient for low hot-water temperatures. Falling-film generators should be used for such applications, because they enable optimum design and production costs.

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4 REFERENCES

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Prejeto:
Received: 15.8.2000

Sprejeto:
Accepted: 10.11.2000