COABSORBENT CYCLE TECHNOLOGY FOR LOW GRADE SOURCES THERMAL RECOVERY

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ABSTRACT

Based on the coabsorbent cycles, recently introduced by the author, a particular new technology can be developed for feasible heat pumping applications. One of its main important features is its high potential in the thermal recovery of low grade natural or industrial heat/sink pairs of sources, usually outdistanced by 25 to 40°C, for efficient heat pumping and power production. After a short introduction of the coabsorbent cycle principle, the paper presents a few theoretical applications of heating and cooling with hybrid/absorption truncated and nontruncated coabsorbent cycles, supplied by different sources. In one of them, the possible coupling of the coabsorbent technology with the existing thermal power stations is proposed and studied from the district heating and cooling point of view. Power applications are also analyzed in conjuncture with different heat/sink natural/industrial sources, emphasizing the direct coabsorbent cycle based power generation role which this could play in the future for clean power production. A final application is related to the multi-functional coabsorbent units which could use low grade heat/sink sources for combined or separate heating, cooling and power production and could be characterized by efficiency and a compact design.

1. INTRODUCTION

The coabsorbent cycles, including the nontruncated and the truncated ones, new cycles with pressure and concentration stages and the multi-effect advanced cycles transposed into coabsorbent operation, recently introduced in previous works, (Staicovici, 2006a – 2007d), base a new emerging technology with high potential in efficient and feasible heat pumping applications and power production, when supplied by high or low grade temperature sources. This paper presents some typical low grade sources thermal recovery coabsorbent applications for heat pumps, refrigeration and power production, with theoretical model results, for hybrid and absorption cycles, operated by the ammonia/water, which this excellent working combination qualities of are best put in opera with coabsorbent cycles only. As a general feature, all coabsorbent cycles are supplied by a pair of heat/sink sources, which are characterized by a certain availability (capacity) and a temperature outdistance (gap) between them, which usually is about 25 to 40 °C (the higher, the better).

2. BASIC, NONTRUNCATED HEATING AND COOLING COABSORBENT CYCLES

For the sake of completeness, the basic ideas of the coabsorbent cycles are remembered first. So far, the absorbent administration in an absorption cycle with condensation or resorption of generated vapour, including two or more subcycles (interconnected by mass and/or heat transfer), bases on a common, known practice that, in short, could be expressed by “a separate absorbent flow in each individual subcycle”. In a previous work, a recent research begun by the author (Staicovici, 2006a) is proposing a new type of absorption cycles, with a different absorbent administration, and named “with co-absorbent”, or simpler, *coabsorbent cycles*. In this way, all condensation and resorption cycle problems (e.g. reduced solubility field, rectification need, absorbent migration, cycle complexity increase with COP improvement, or diminished returns COP with cycle complexity increase) could be avoided, if coabsorbent cycle were used. The coabsorbent cycle is built up by joining the resorption cycle subcycles along a common isostere ($y = y_M = const.$), so that the opposed pair processes, of generation and resorption, and of absorption and desorption, are isobar and in mass (vapor) and heat exchange, and the subcycles separate absorbents have a common point "M" (mixing point), where are mixing and cyclic regenerate the absorbent mean concentration, y_M. By joining upon temperature decrease two cooling + heating type subcycles, it is obtained a *nontruncated cooling coabsorbent cycle*, Figure 1a, and by joining upon temperature decrease two heating + cooling type subcycles, it is obtained a *nontruncated heating (heat transformer) coabsorbent cycle*, Figure 1b, (Staicovici, 2006a). The nontruncated coabsorbent cycles are new, individual basic thermodynamic absorption cycles, and have particular flow and heat properties.

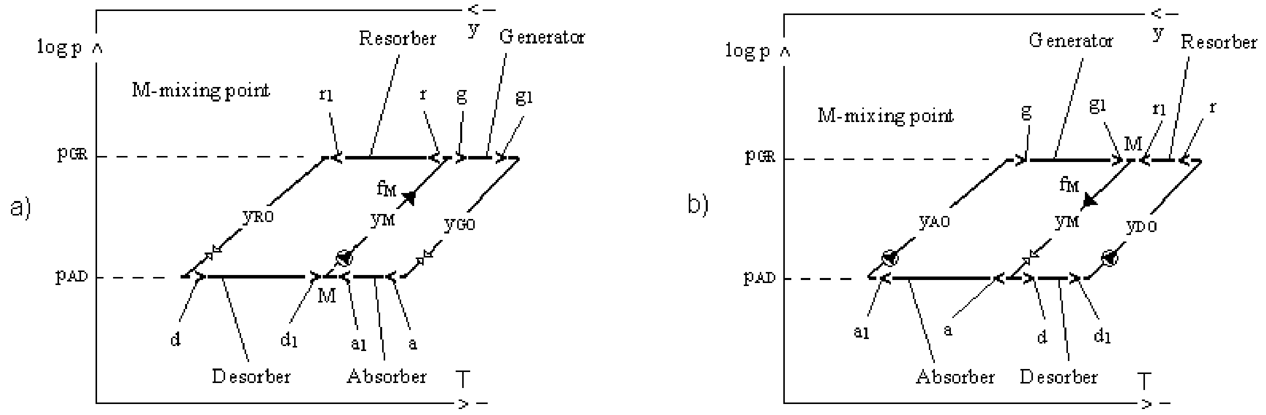
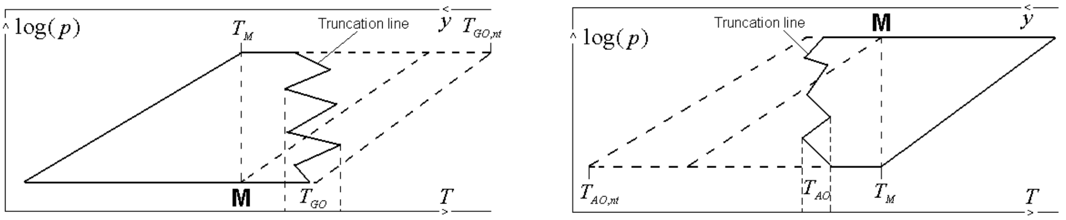


Figure 1. Cooling (a), and heating (b) nontruncated coabsorbent cycles.

3. A FEW NEW COABSORBENT CYCLE CONFIGURATIONS

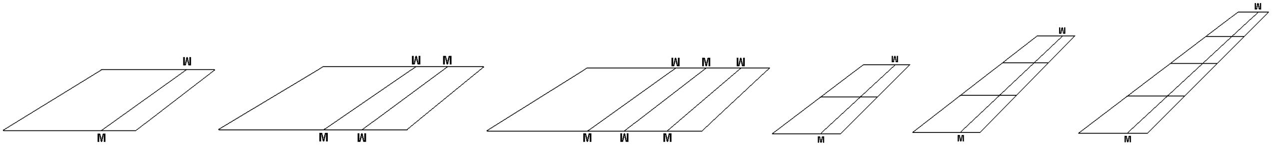
Starting from the nontruncated coabsorbent cycles, countless coabsorbent ones can be conceived. This is why cycles selection is mandatory. The simplest are derived by composing the nontruncated and truncated cycles (Staicovici, 2006f, 2006g, 2007b). Truncation requires a special technique, (Staicovici, 2006d, 2006g), which enables a better cycle source-task match, Figures 2a-b. Truncated cycles COP is generally favoured, as compared to those with condensation and resorption, because they completely eliminate vapour rectification and have gliding heat exchange with sources. Additionally, due to the large concentration intervals which the opposite absorption / desorption processes are operating with, their temperatures are frequently overlapping, so that the GAX effect can be used. Also, internal recovery heat exchange of solution/solution and solution/gas types is mandatory for COP increase. The truncated and nontruncated cycles are intrinsic related one to each other from a topologic and absorbent flow point of view, and this makes them to behave as fractals, wherefrom, nontruncated coabsorbent cycles are termed *cooling* and *heating fractals*, (Staicovici, 2006g). The new simplest coabsorbent cycles can be derived by adding a convenient number of concentration stages (Figure 3a-c) or pressure stages (Figure 3d-f) to the basic nontruncated cycles



a) b)

Figure 2. Truncation of the coabsorbent cycles: a) cooling cycle; b) heating cycle.

(all cycles are plotted in the log p – 1/T (Mollier) diagram). Mixing points are noted by M and upset M for the nontruncated cycles of origine of refrigeration and heating type, respectively. They have application in the combined cooling and heating and in the transposition of the known multi-effect absorption cycles into coabsorbent technology (Staicovici, 2006a, 2006g). The transposition favours absorption technology by (Staicovici, 2006a, 2006g, 2007d): a) linear (instead of diminished returns) COP increase; b) exergy efficiency increase (generator temperature substantial decrease for same COP), and c) cycle complexity decrease.



a) b) c) d) e) f)

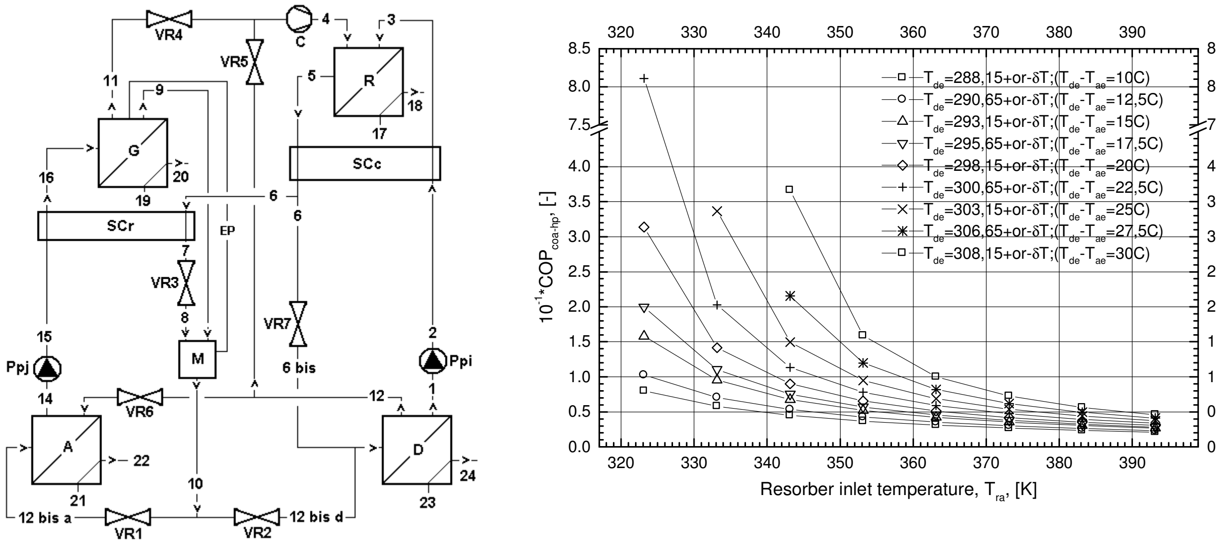
Figure 3. Simple (a), double (b) and triple (c) concentration stages, and double (d), triple (e) and quadruple (f) pressure stages coabsorbent cycles.

4. LOW GRADE SOURCES THERMAL RECOVERY IN COABSORBENT TECHNOLOGY APPLICATIONS

Next, we shall give a few results of heating, cooling and power coabsorbent technology applications, having absorption and hybride operation with low grade sources.

4.1. Coabsorbent Cycle Hybrid Heat Pump

We start with the simplest coabsorbent cycle hybrid heat pump, operated by NH_3/H_2O (Staicovici, 2006a, 2006b), schematically given in Figure 4a. The heat pump can work as a hybrid coabsorbent cycle, when the four devices, R, G, A, and D are implied, or as a wet resorption hybrid cycle (Osenbrück), with R and D devices, only. The heat pump was initially designed for domestic heating purposes (R inlet at 333,15 K). Sources for G and D were considered ground for winter operation, and waste heat, or air, for summer operation, and those for A, cold air in winter, and ground in summer.



a) b)

Figure 4. a)-coabsorbent hybrid heat pump: Resorber, Generator, Absorber, Desorber, SC=HE, Mixer, Pump, Compressor, VR-valve; b)-NH_3/H_2O coabsorbent hybrid heat pump heating COP (adiabatical single-stage vapor compression; mechanical efficiency = 0.9; resorber maximum temperature: $T_{ra} = (323.15 \text{ to } 393.15) - \text{or} + \Delta T$, where $\Delta T = 0$ to 10 °C; absorber minimum temperature: $T_{de} = 278.15 + \text{or} - \Delta T$; mixer concentration: $y_{mix} = 0.7$; absorber outlet concentration: $y_{mix} + 0.05$).

The heat pump COP, was modeled for a whole year operation. Results are given in Figure 4b, against resorber inlet temperature, with ($\Delta T =$desorber max. temperature-absorber min. temperature=10; 12.5; 15; 17.5; 20, 22.5; 25; 27.5 and 30 C) as parameter. The COP values are by 2.5 to 3 times higher than those calculated for the usual vapor compression heat pumps, encouraging its use in medium and high capacity heating applications.

4.2. Coabsorbent Cycle Hybrid Refrigeration Plant

Using a similar hybride scheme, as in Figure 4, (Staicovici, 2006c), a very high COP cooling plant can be obtained this time for industrial cooling and refrigeration, $T_{DO} = (213{,}15 - 263{,}15)K$. The model results are given in Figure 5 for $\Delta T = 20C$, in two slightly different domains, with sink sources of 278.15 and 288.15 K, and heat sources of 298.15 and 308.15 K. Again, the COP values are higher than those calculated for the usual vapor compression refrigeration plants, challenging the CO_2/NH_3 cascade system in industrial cooling and encouraging its use in medium and high capacity cooling applications. It is worth mentioning also, that the cycle is capable to simultaneously produce heat effect (cogeneration of cooling and heat), which is quantified in same figure as well.

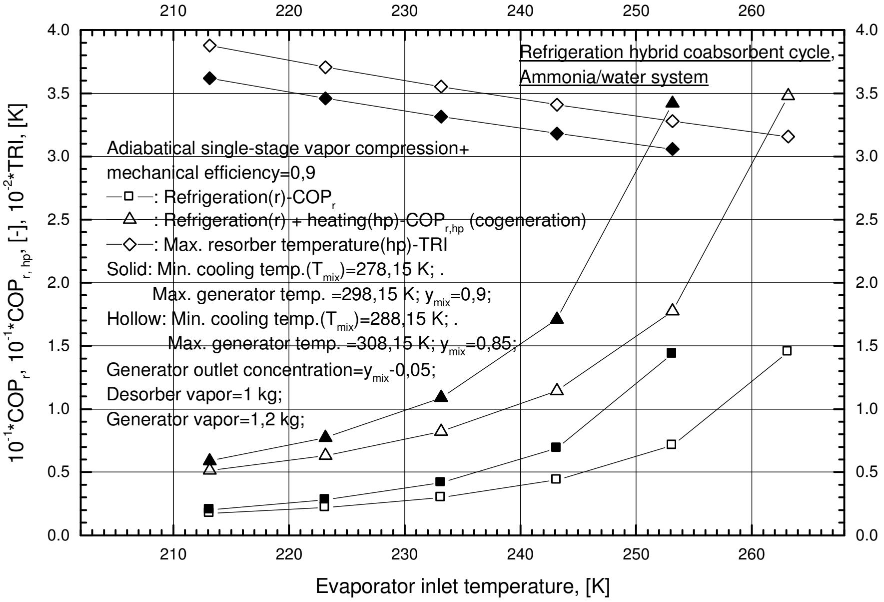
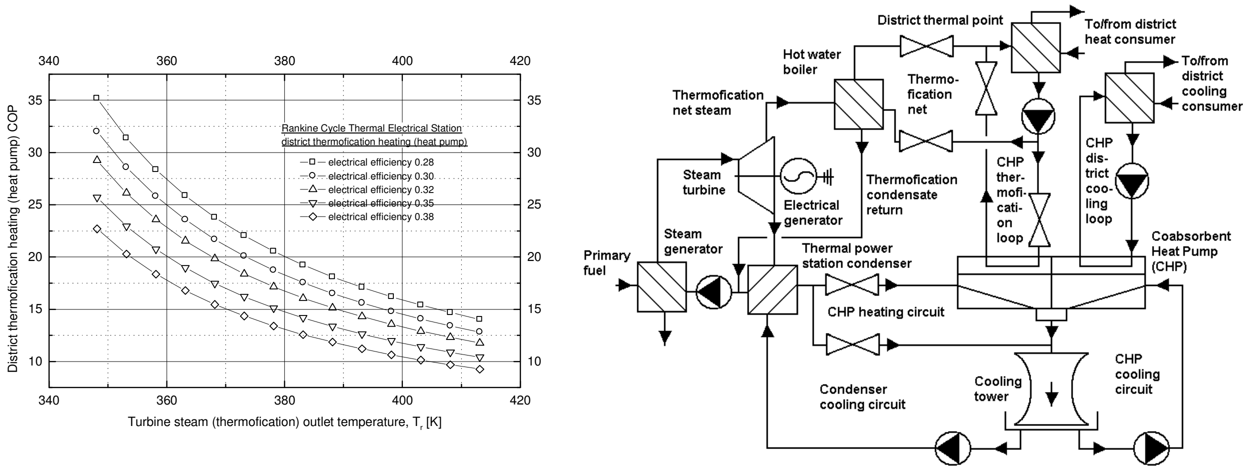


Figure 5. NH_3/H_2O coabsorbent hybrid cooling (-60)-(-10 C) and heating (40-110 C) model.

4.3. Coabsorbent Cycle -Thermal Power Plants Coupling For District Heating And Cooling

Thermofication is a very efficient way to heat the district, sacrificing a small amount of power plant electrical power, only. A simple estimate of thermofication efficiency, regarded as a heat pump effect, useful in our application, is given in Fig. 6a, (Staicovici, 2007a, 2007b-e). Due to its high efficiency potential, the coabsorbent cycle technology offers the opportunity to couple the coabsorbent heat pumping plants with thermal power stations for district heating and cooling, increasing the thermal power plant global efficiency (up to 90 percent), for the environment, electrical power producers and heat and cooling transport, distribution and consumption benefit. The technical solution, given in Fig. 6b, (Staicovici, 2006e, 2006f, 2007b-e), bases on a known heat pump use in condensation turbine power plants (Radcenco *et al.*, 1985), which couldn't be effectively applied so far, especially in Romania, because of the low heat pumps COP and power station electrical efficiency. According to our solution, a fraction of the free low grade condenser heat, at 40 to 50 C, is powering the coabsorbent plant generation + desorption devices, on one side, and a fraction of the tower cooled condenser cooling water, at 10 to 30 C, is cooling the absorption coabsorbent plant device, on the other side. In this way, the heat pump is delivering heat at 80-160 C, at very high efficiency (COP=50 to 150), extending the thermofication process. Similarly, a coabsorbent hybrid refrigeration plant can be coupled with the thermal power station, Fig. 6b, in order to deliver most efficient cooling (-60 to -10 C, COP=50 to 200). Figure 7 shows estimated year round electrical power savings potential in district heating, $[W_{electrical}/W_{thermal}]$, against heat pump desorber inlet temperature, when using truncated coabsorbent heat pumps coupled with thermal power plants, instead of the thermofication. Savings are quite small in this case and the gain in COP is counterbalanced by a heating capacity decrease (2 to 6 times), as compared to the thermofication, so our solution should be applied for power plant district heating/cooling global capacity increase, rather than to replace thermofication. Table 2 gives the heating COP obtainable in this application type, for different sink sources supplying the coabsorbent heat pump (tower cooling, ocean and ambient air), during winter and summer time.



a) b)

Fig. 6. Thermofication efficiency assessment (a); district heating and/or cooling flow chart using a coabsorbent heat pumping plant-thermal power station coupling (b).

The proposal outlined above is extremely important, as it indicates a possible future way of combined power, heating and cooling production with one of the highest global efficiency ever met in energetics so far. Indeed, unlike the current way to proceed, when refrigeration and heating applications were optimized separately, without taking into consideration the supplying power source, in this case, the multi-functional (power, cooling and heating) system is energetically optimized, considering it globally, with emphasis to the primary energy consumption minimization. In completion, however, the reader might think that our proposal would be limited in application to a small area around the thermal power station, with a radius of say up to 2-3 km. This would be true enough, if we had taken into consideration the actual situation only, when the big cities are electricity supplied by several high capacity electrical power plants, with at least 500 to 1000 Mwe each. However, this drawback could be overcome, if the high capacity power plants were replaced in the future by a number of smaller capacity inter-connected power plants, of say up to 50 to 100 Mwe each, distributed in the whole district, with an equivalent power, sensibly same high electrical efficiency, and provided with coabsorbent technology, in order to meet all kinds of energy (power, heating and cooling) required in the district. The result would be of an enormous advantage for the environmrent protection and district heating and cooling, given the highest efficiency this system would have, and the fact that the greatest combined enegy consumption is in cities, crowded by people and industrial facilities, not in remote areas. As a first step, the power plants are thought of combined type, with gas turbines and electrical efficiency of up to 0.55 (eg IGCC), powered by gas fuel. In a second step, these could be replaced by clean power technologies plants, with biofuel supply, or with CO_2 mitigation (eg. COOLENERG process, Staicovici, 2003a-b), etc.

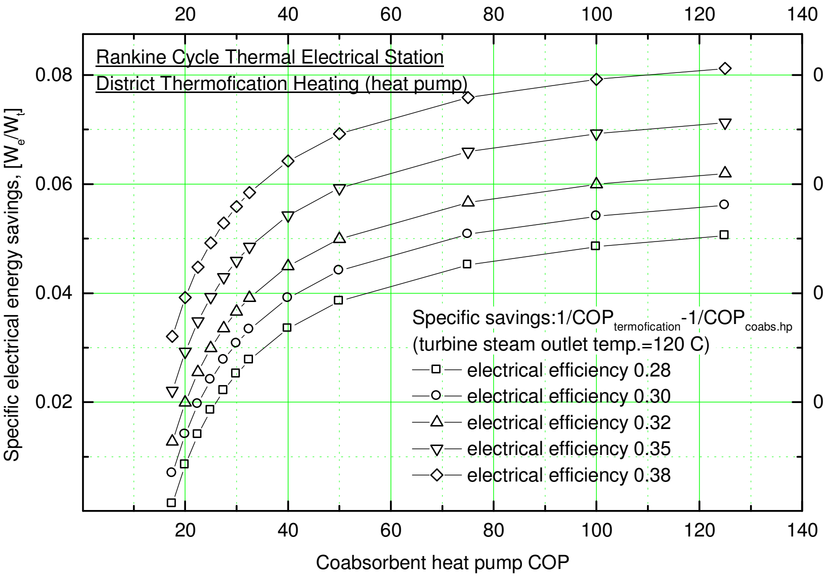


Fig. 7. Assessed year round electrical power savings in district heating versus coabsorbent heat pumps COP, using a coabsorbent heat pump-thermal power coupling, instead of thermofication.

4.4. Truncated Coabsorbent Cycle Refrigeration

Simple truncated cooling cycles were modeled for refrigeration and air-conditioning. Results are given in Figures 9a-b, respectively. Generator temperatures, $T_{GO} = 363.15 - 383.15K$, are low (waste or solar energy), but the COP values, calculated for multi-temperature source generation cycles, are double to triple as compared to those of condensation refrigeration cycles for same working parameters (cooling temperature 303.15 K).

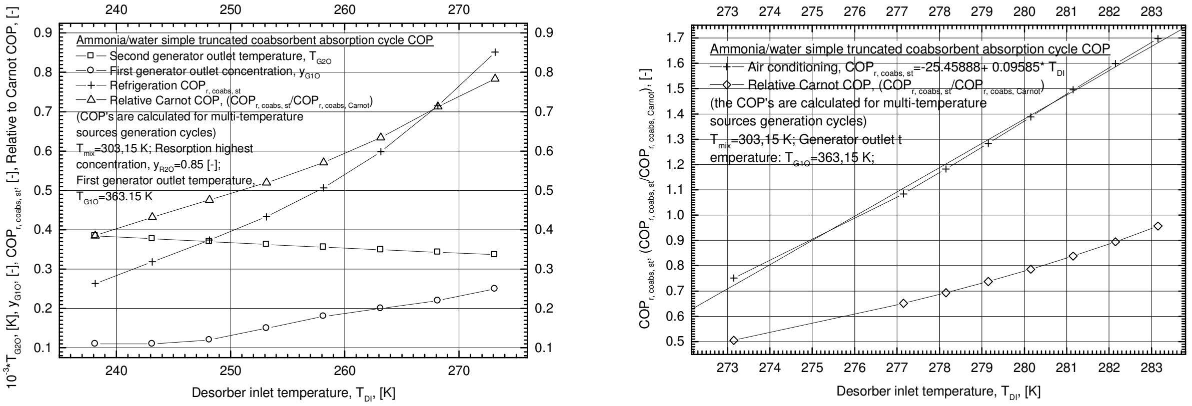


Figure 9. NH_3/H_2O simple truncated coabsorbent cycle COP best powered by waste or solar energy for: a) normal freezing (0 to -35 C); b) air conditioning.

4.5. Coabsorbent Technology Power Production

The coabsorbent technology offers the unique opportunity to feasibly produce power, using pairs of low grade heat / sink sources. Table 1 gives model results of coabsorbent - Rankine power production with several natural / industrial low grade heat / sink pairs of sources and NH_3/H_2O. Sources are free, except the solar thermal which needs solar collector investments, and their availability is enormous. This is why, despite of the low conversion efficiency (last column in Table 1), the coabsorbent technology is capable to participate with increased capacity, together with the other renewable energy based ones, to the clean power production process at present and in the furture.

Table 1. Coabsorbent technology power production by natural-industrial low grade heat / sink sources.

Heat source Sink source	Sources temperatures $[C]$	Cycle temperature gap $(T_{GO}-T_{RO})$, $[C]$	Net power output $[W]$	Efficiency $\left[\frac{\eta_W}{\eta_{Carnot}}\right]$
1	2	3	4	5
Planet warm sea surface Sea deep	303.15^{*} 278.15^{**}	20	112.7^{***}	0.0257 0.0665
Solar, geothermal Tower cooling	368.15 303.15	60	256.3	0.0526 0.164
Solar, geothermal Air cooling	378.15 313.15	60	234.3	0.05 0.16
Icy sea Cold air	273.15 248.15	20	142.2	0.03 0.0739
Thermopower station Sea	313.15 278.15	30	177.1	0.0378 0.0966
Thermopower station Cold air	313.15 248.15	60	385.3	0.0686 0.193
Thermopower station Icy sea	313.15 273.15	35	203.3	0.0413 0.113
Icy sea Arctic air	273.15 223.15	45	362.0	0.0629 0.166

*) / **) Source-task temperature gap=2.5 C; ***) Turbine isentropic efficiency=0.85; Solution pump efficiency=0.6.

4.6. Coabsorbent Heat Pumps COP For Several Heat / Sink Sources Pairs

Hybrid heating fractal and truncated heating fractal heat pumps, have been modeled for summer - winter operation, different low grade heat / sink pairs of sources and useful heat (task) temperatures, in case of residential and district heating applications. In our study we used simple to quadruple truncated columns (Staicovici, 2006d, 2007e). The model input data and results are given in Table 2. Mean heating COP, column 6, show several to hundred times higher values as compared to those of the compression heat pumps for each application. However, heat pumps capacity (last column), defined as (useful heat units / heating source heat units), indicate that about 1/2 to 1/6 of the heating source becomes useful only, so a designer has to find the heat pump optimal configuration and thermal performance, taking into account sources availability as well.

Table 2. Hybrid heating fractal and truncated heating fractal coabsorbent heat pumps operation data for summer-winter and several heat / sink pairs of sources and useful heat temperatures.

Period	Heating source Cooling source	Sources temperatures (C)	Useful heat temperature (C) HHF* - THF**	Application	Mean heating COP HHF - THF	Capacity HHF - THF
1	2	3	4	5	6	7
Winter	Ground Ambient air	(+5) – (+7) (-20) – (-4)	62 – 62	Residential	3.82 – 5.2***	0.49 – 0.33
	Underground water Ambient air	(+12) – (+14) (-20) – (-4)	67 – 67	Residential	4.74 - 208	0.48 – 0.21
	Thermopower station condenser cooling water Tower cooled water	(+40) – (+55) (+10) – (+15)	117 – 117	District	4.68 – 57	0.45 – 0.17
	Thermopower station condenser cooling water Ocean (sea) water	(+40) – (+55) (+5) – (+8)	117 – 132	District	5.69 – 27.5	0.45 – 0.14
	Thermopower station condenser cooling water Ambient air	(+40) – (+55) (-20) – (-4)	117 – 117	District	15.75 - 180	0.46 – 0.33
Summer	Ambient air, waste heat Ground	(+30) – (+40) (+5) – (+8)	67 – 96	Residential	10.69 – 92.16	0.45 – 0.19
	Ambient air, waste heat Underground water	(+30) – (+40) (+12) – (+14)	62 – 76	Residential	7.97 – 80.86	0.45 – 0.23
	Solar energy Ground	(+25) – (+35) (+5) – (+8)	67 – 75	Residential	7.3 – 92.65	0.46 – 0.22
	Solar energy Underground water	(+25) – (+35) (+12) – (+14)	62 –	Residential	7.62 –	0.48 –
	Thermopower station condenser cooling water Tower cooled water	(+40) – (+55) (+25) – (+35)	77 – 90	District	8.38 – 55.52	0.47 – 0.24
	Thermopower station condenser cooling water Ocean (sea) water	(+40) – (+55) (+10) – (+20)	77 – 122	District	22.77 – 73.93	0.47 – 0.17

*) Hybrid heating fractal; **) Truncated heating fractal; ***) Simple truncated hybrid heating fractal; Source-task temperature gap=2.5 C; Solution pump efficiency=0.6.

4.7. Complex Coabsorbent Systems For Power, Heating And Cooling Production

Separate useful effect units can be joined in a single multi-functional coabsorbent unit for simultaneously or separate power, heating and cooling production. For operation, the resulting joined unit would be supplied by a same low grade heat / sink sources pair, as that needed for the individual units, but with a correspondingly increased capacity. The COP's are the same as those of individual units, that is very high for heating (see Table 2) and similarly for cooling. The power efficiency is similar to those mentioned in Table 1, for similar sources pairs. A multi-functional unit is resulting with a compact design, as the component devices having same function and same working parameters can be replaced by a single one in the coabsorbent technology. More technical details about this item will be given in papers to follow.

5. CONCLUSIONS

The paper presents a few typical coabsorbent technology applications, supplied by natural / indstrial low grade heat / sink sources pairs. All applications emphasize the high potential of this emerging technology in the primary energy savings and recommend its immediate translation in practice, for future clean heating, cooling and power production.

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