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Investigation Effective Parameters of a Diffusion Absorption Refrigeration Cycle Coupled with a Solar Parabolic Collector

Peyman Behmanesh[a*], Ali Bolkhari Ghahi[a], Majid Bazargan[b]

[a] *Department of Mechanical Engineering, K. N. Toosi University of Technology, Tehran, Iran; *Email:peyman.beh@gmail.com*

[b] *Department of Mechanical Engineering, K. N. Toosi University of Technology, Tehran, Iran*

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A B S T R A C T

This study embraces a steady numerical simulation of thermodynamic model optimized for an ammonia-water diffusion absorption refrigeration (DAR) cycle with hydrogen or helium as the auxiliary gas. A DAR cycle has been examined due to the fact that such cycles may operate under low cooling load without a mechanical pump. To this end an Electrolux refrigerator manufactured by Dometic of Sweden is examined. The generator of this system has been modified to have it coupled with a parabolic trough collector in order to enhance the heat transferred to the generator. Besides, considering temperature range gained by the collector, the DAR cycle has been optimized. Finally, the results are validated against available experiments. It was found that the effects of parameters such as generator temperature, ammonia solution concentration, pressure of the cycle and the temperature of the main components of the cycle can change the COP by ±10% .

1. Introduction

Solar refrigeration is created by two ways, namely cycles with heat input and cycles with photovoltaic source. Heat-driven systems are utilized mostly with the aim of air conditioning. The absorption systems are the only ones used to create below zero degree temperatures for refrigeration purposes. The driving temperature for each of these cycles depends on the type of the cycle, refrigerant fluid, the absorber and the pressure of the generator.

Many investigations have been carried out on the diffusion absorption refrigeration cycles. Some mathematical models estimate a maximum COP of around 0.15 for such cycles, while the experimental measurements suggest the possibility of improving COP coefficients up to 0.2 [1]. Valizadeh and Ashrafi [2] studied a continuous solar refrigerator by coupling a collector and thermal battery. It was consisted of a solar collector, a solar thermal battery, heat transfer equipments and the refrigerator compartment. The effect of spraying water on the condenser of the refrigerator was investigated. The spraying water was shown to have remarkable effects on decreasing the temperature of the evaporator of the refrigerator. The lowest temperature of -19^{o}C was reached.

Gutiierrez [3] studied a diffusion absorption system with working fluids of water and ammonia. The collector was flat.

Since no storage system was considered, it could not work continuously and did the refrigeration merely during the sunny hours. The condenser of this system was designed as natural-convection air cooling. The effects of the environment temperature on the equipment and system were experimentally studied.

The diffusion absorption cycle running by water-ammonia and the inert gas Helium was studied by Srikhirin and Aphornratana [4]. They carried out tests for obtaining the performance of the bubble pump. Heat source was provided by electrical energy. The effects of the input energy to the generator on the COP and the refrigeration effect were reported.

Wang et al.[5] published the results of a computational research on diffusion absorption refrigerators which worked with a combined R134a/R23, Dimethylformamide absorber (DMF) and the inert gas Helium refrigerant. The results of this study showed that the COP of the DAR depends on the factors such as generator temperature, environment temperature, evaporator temperature, system pressure, combination of solutions, rectifying ability of solution and the ratio of helium to refrigerant. All mentioned parameters were investigated in detail and the capability of the system to supply low temperatures around -40^{o}C was demonstrated.

Researches by Starace and Pascalis [6] resulted in developing a thermodynamic model for a diffusion absorption refrigerator cycle. It could be considered as the development of the previous model proposed by Zohar et al. [7]. In this model, the assumption of purity of the refrigerant which is the output of the bubble pump did not exist. Comparing the proposed model with the Zohar et al. Model [7], the results showed 2 to 8.5 percent difference which is mainly due to the mentioned assumption.

Since suitable performance of the bubble pump has a significant influence on the performance of the diffusion absorption cycle, its efficient design is very important. This was one of the main focuses of the work of Starace and Pascalis [8]. They carried out a research on diffusion absorption refrigerators with concentration on the thermal pump. Also using a microwave source they tried to significantly lower the transition and starting time of the refrigerator.

Mazouz et al [9] presented suitable data in order to design a refrigerator based on the diffusion absorption cycle. They considered a water/ammonia solution with auxiliary gas hydrogen type and an electrical heater as the input energy to the generator. The purpose was to obtain a proper design to address the need for keeping perishable foodstuffs and drugs in regions which are deprived of electricity. This can be done by designing and manufacturing solar refrigerator.

1.1. Diffusion Absorption Refrigeration (DAR)

The diffusion absorption cycles based on three materials of water, ammonia and hydrogen (in some cases helium) are investigated in this study. A schematic of the cycle is shown in "Figure 1". Ammonia vapor is separated from dense fluid in the generator (a1). Vapor bubbles flow upward in the bubble pump. At the point (1c), water-ammonia vapor and dilute fluid exit from the pump. Then, vapor mix flows in the rectifier and the existing water vapor is added to the weak solution (1e) after condensation (1d). Pure ammonia flows toward the condenser after point (2) and after condensation at the point (3), ammonia liquid flows toward the evaporator. A secondary path for bypassing the remaining ammonia in vapor phase is provided in this section which sends out the vapor towards the reservoir.

In the way of entering the expansion chamber, the ammonia pipe passes along the evaporator and is in thermal contact with it in order to turn into a cold liquid. At the evaporator entrance, cooled ammonia (4a) is mixed with the hydrogen supplied from the absorber (4b) which has become colder by passing through the heat exchanger. The result of this mixture is a little pressure drop in ammonia and creation of refrigeration effect. The evaporator and the vapor exchanger are in fact placed as shell and tube exchanger where the returned hydrogen from the absorber flows in the inner pipe and the ammonia-hydrogen mixture flows in the shell. This mixture is returned to the absorber after passing through the ice-maker and refrigerator chamber and absorbing heat from the foodstuffs (5b) and traverses in the opposite direction of the absorber from the bottom so that its ammonia is separated by the dilute solution flowing in the absorber (10-9a). The result of this process is that the input solution to the reservoir becomes dense (10) and hydrogen is separated. The resulting dense solution flows towards the generator (6) and is preheated a little by passing through the exchanger in this path.

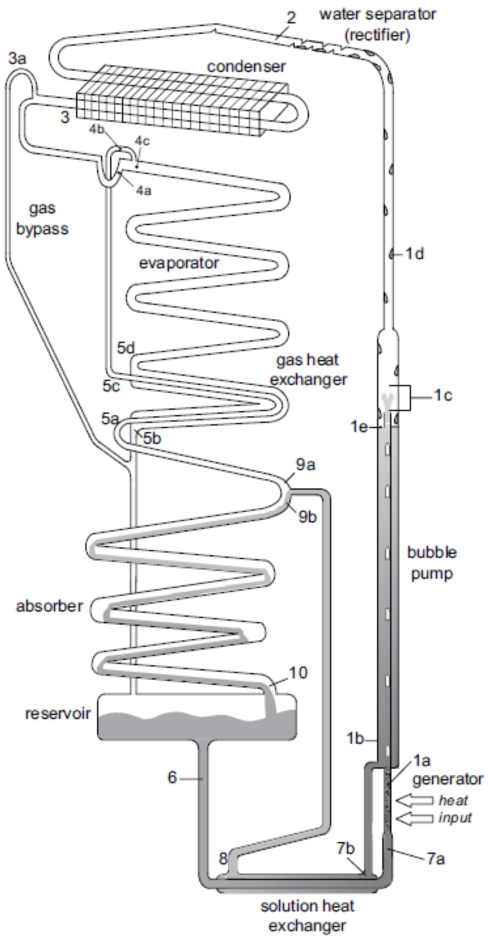

Figure 1. schematic of parts and key points of disfussion absorption cycle [7]

2. Materials and Methods

2.1. Cycle

The proposed model is an absorption cycle of water, ammonia and hydrogen which is shown in Figure 2. Ammonia as a water absorbant and hydrogen as an auxillary gas are used. The collector provides heat to be added to the generator at the submerged section of the bubble pump.This cycle is precisely the same as the cycle of oil refrigerators. Before condensor, rectifier sepearates water vapor from ammonia vapor. The condensation water returns to the generator and ammonia water is guided to the condensor. Ammonia vapor losts its heat in the condensor while it transforms to the liquid phase. Because of the high pressure of the fluid in the condensor, ammonia liquid interact with the hydrogen before entring the evaporator, so its pressure will be reduced extremely. Then, the ammonia absorbs the surrounding heat that leads to change to the low pressure gas. Ammonia is abosrbed by water in the absorber and seperates from hydrogen gas which is returned to the entrance of the evaporator. Regarding hydrogen seperation, the pressure fluid will be increased and enters the heat exchanger. In this part, the high concentration fluid and the low concentration fluid which is returned from the generator are preheated and enter the generator. Ammonia seperates from water because of gaining heat in the generator, so enters the rectifier and the cycle is repeated. [10]

The diffusion absorption cycle has only one distinct pressure and the diffrence between the partial pressure which is related to the heat absorption is responsible for the current flow. The ratio of the absorbant pressure to the auxiliary gas partial pressure is 1:20. For instance, referring to this cycle, the pressure diffrence range is 25 up to 75 kPa.

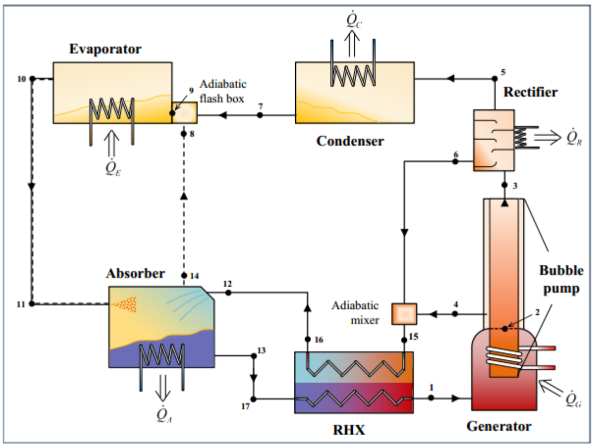

Figure 2. The solar diffusion absorption cycle in this study [11]

2.2. Equations

All of the cycle processes are regarded steady state. The following lines show the mass, momentum and energy equations of each components. [12],[13]

$$P = P_x + P_y + P_z \quad (1)$$

$$P_{sys} = P = P_{NH_3} + P_{aux} \quad (2)$$

$$COP_{AH} = \frac{Q_E}{Q_G} \quad (3)$$

Rectifier:

$$\dot{m}_6 + \dot{m}_5 = \dot{m}_3 \quad (4)$$

$$P_5 = P_3 - \rho g(z_5 - z_3) - \Delta P_R \quad (5)$$

$$P_6 = P_3 - \rho g(z_6 - z_3) - \Delta P_R \quad (6)$$

$$\dot{Q}_R + \dot{m}_6 h_6 + \dot{m}_6 g z_6 + \dot{m}_5 h_5 + \dot{m}_5 g z_5 = \dot{m}_3 h_3 + \dot{m}_3 g z_3 \quad (7)$$

Condenser:

$$\dot{m}_7 = \dot{m}_5 \quad (8)$$

$$P_7 = P_5 - \rho g(z_7 - z_5) - \Delta P_c \quad (9)$$

$$\dot{Q}_c + \dot{m}_7 h_7 + \dot{m}_7 g z_7 = \dot{m}_5 h_5 + \dot{m}_5 g z_5 \quad (10)$$

Mixing chamber:

$$\dot{m}_7 = \dot{m}_9 \quad (11)$$

$$P_9 = P_7 - \rho g(z_9 - z_7) - \Delta P_{Fb} \quad (12)$$

$$\dot{m}_7 h_7 + \dot{m}_7 g z_7 = \dot{m}_9 h_9 + \dot{m}_9 g z_9 \quad (13)$$

$$\dot{m}_8 = \dot{m}_{aux,9} \quad (14)$$

$$P_{aux,9} = P_8 - \rho g\left(z_{aux,9} - z_8\right) - \Delta P_{Fb} \quad (15)$$

$$\dot{m}_8 h_8 + \dot{m}_8 g z_8 = \dot{m}_{aux,9} h_{aux,9} + \dot{m}_{aux,9} g z_{aux,9} \quad (16)$$

Evaporator:

$$\dot{m}_9 = \dot{m}_{10} \quad (17)$$

$$\dot{m}_{aux,9} = \dot{m}_{aux,10} \quad (18)$$

$$P_{10} = P_9 - \rho g(z_{10} - z_9) - \Delta P_E \quad (19)$$

$$(\dot{m}_{10} h_{10} + \dot{m}_{10} g z_{10}) + (\dot{m}_{10} h_{10} + \dot{m}_{10} g z_{10})_{aux} = \dot{Q}_E + (\dot{m}_9 h_9 + \dot{m}_9 g z_9) + (\dot{m}_9 h_9 + \dot{m}_9 g z_9)_{aux} \quad (20)$$

Absorber:

$$\dot{m}_{13} = \dot{m}_{12} + \dot{m}_{11} \quad (21)$$

$$\dot{m}_{aux,11} = \dot{m}_{14} \quad (22)$$

$$P_{13} = P_{11} - \rho_l g(z_{13} - z_{11}) - \Delta P_A \quad (23)$$

$$P_{13} = P_{12} - \rho_g g(z_{13} - z_{12}) - \Delta P_A \quad (24)$$

$$P_{14} = P_{aux,11} - \rho_g g(z_{14} - z_{11}) - \Delta P_A \quad (25)$$

$$(\dot{m}_i h_i + \dot{m}_i g z_i)_{11+12} + (\dot{m}_i h_i + \dot{m}_i g z_i)_{aux,11} = \dot{Q}_A + (\dot{m}_i h_i + \dot{m}_i g z_i)_{13+14} \quad (26)$$

Heat Exchanger:

$$\dot{m}_1 = \dot{m}_{17} \quad (27)$$

$$\dot{m}_{16} = \dot{m}_{15} \quad (28)$$

$$P_1 = P_{17} - \rho g(z_1 - z_{17}) - \Delta P_{HX} \quad (29)$$

$$P_{16} = P_{15} - \rho g(z_{16} - z_{15}) - \Delta P_{HX} \quad (30)$$

$$(\dot{m}_i h_i + \dot{m}_i g z_i)_1 - (\dot{m}_i h_i + \dot{m}_i g z_i)_{17} = (\dot{m}_i h_i + \dot{m}_i g z_i)_{15} - (\dot{m}_i h_i + \dot{m}_i g z_i)_{16} = \dot{Q}_{HX} \quad (31)$$

$$\frac{1}{U} = \frac{1}{h_o} + \frac{d_o}{d_i h_i} + \frac{d_o \ln\left(\frac{d_o}{d_i}\right)}{2K_w} \quad (32)$$

$$q = UA\Delta T_m \quad (33)$$

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (34)$$

$$\varepsilon = \frac{q}{q_{max}} = \frac{UA\Delta T_m}{C_{min}(T_{h,i} - T_{c,i})} \quad (35)$$

Generator:

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_4 + \dot{m}_3 \quad (36)$$

$$P_3 = P_1 - \rho_g g(z_3 - z_1) - \Delta P_G \quad (37)$$

$$P_4 = P_1 - \rho_l g(z_4 - z_1) - \Delta P_G \quad (38)$$

$$(\dot{m}_i h_i + \dot{m}_i g z_i)_{3+4} - (\dot{m}_i h_i + \dot{m}_i g z_i)_1 = \dot{Q}_G \quad (39)$$

Table 1. position height [14]

position	height(m)
1	0
2	0.27
3	0.55
4	0.28
5	0.6
6	0.56
7	0.55
8	0.54
9	0.55
10	0.6
11	0.3
12	0.3
13	0.22
14	0.3
15	0.24
16	0.24
17	0

2.2. Simulation

Table 2.Drop pressure of components [14]

component	Drop pressure (kPa)
Generator	5
Bubble pump	10
Heat exchanger	10
Evaporator	9.42
Condensor	10
Absorber	2.36
Rectifier	17.88
Pipe	P_{in}*0.012

Also these assumption were are considered due to the refrences which is mentioned.[15]

Table 3.Assumptions of important parameters

parameter	value
ε	0.7
$\dot{m}_1$	0.00016 (kg/s)
amoonia concentration	0.4
P_{sys}	15 bar
T_g	120-150 (°C)

To complete the momentum equations, the height and pressure drop of each components must be gained from the catalogue of the actual refrigerator which is to be simulated.

3. Results & Discussion

3.1. Validation

The results are validated against Potgieter [10] to assess the effect of two parameters on COP cycle. Figure 3 and 4 are shown the subtle and appreciable difference between the results.

3.2. Effect of Pressure, Ammonia concentration and Generator temperature

As shown in Figures 3 to 5, although Q_{evap} and Q_{gen} are decreased, COP will be increased owning to the fact that the extent of decrease in Q_{gen} is dominant over the decrease in Q_{evap}. There is significant jump in values of Q before 14 bar in Figure 5 because the condenser could not transform fluid to saturation liquid and its quality is more than zero that causes noisome repercussion on cycle operation.

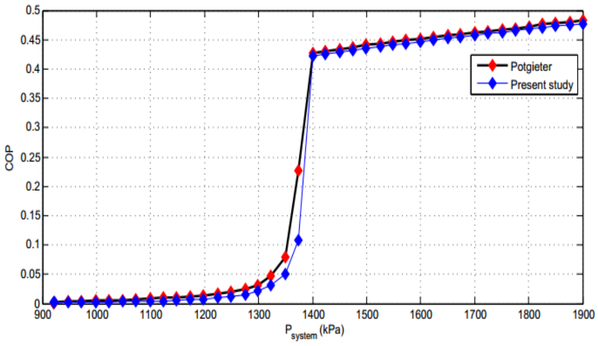

Figure 3. Comparison value of COP against pressure cycle in two studies

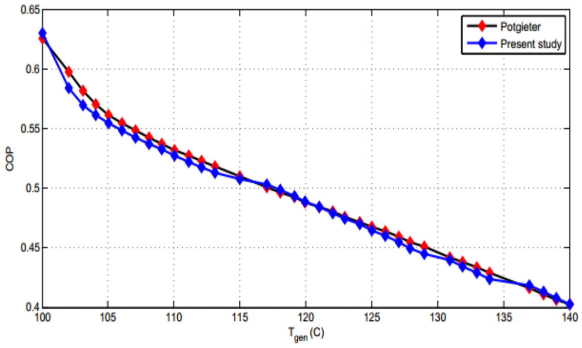

Figure 4. Comparison value of COP generator temperature in two studies

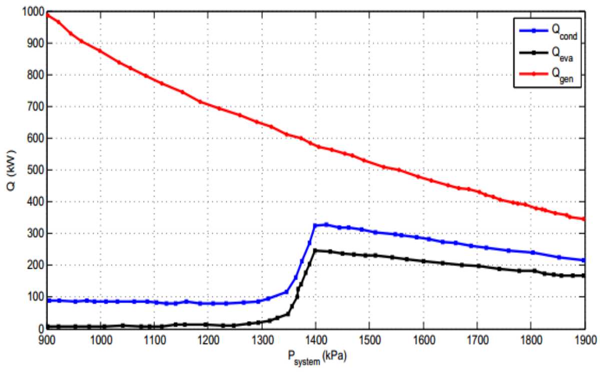

Figure 5. DAR performance with varying generator temperature

Figure 6 shows the variations of COP with the generator temperature. It can be seen that by the increase of the generator temperature in strong solutions of ammonia, COP will be decreased.

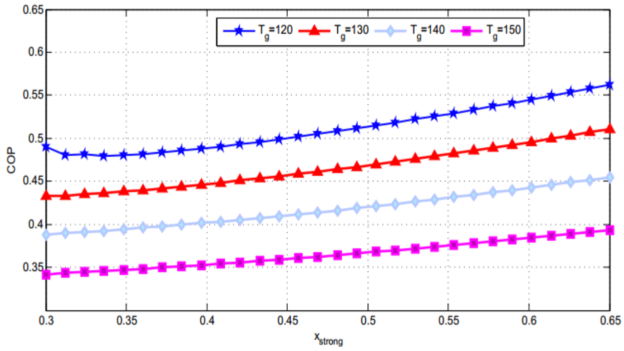

Figure 6. DAR performance with varying generator temperature and concentration of strong ammonia solution

3.3 Optimum ranges

In this article, referring to sutiable range of concentration, generator temperature range provided by the solar parabolic collector, logical series investigation is considered to obtain optimum range for COP and generator temperatire and eventually lower temperature of evaporator.

According to the assumptions which is related to exact quantity of weak and strong ammonia solutions (0.45,0.65), Fig 7 is plotted with constant COP. Based on review articles, we know that 20% is the most concentration difference that can be caused.

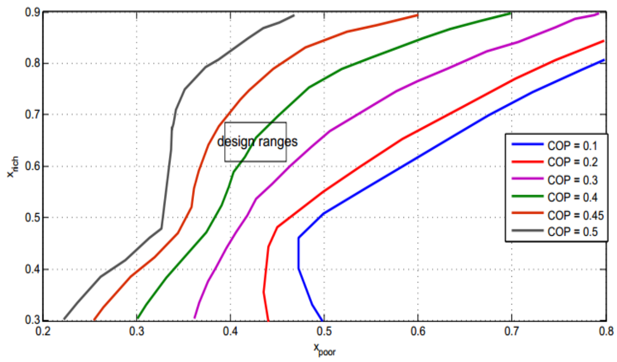

Figure 7. COP contour vs rich and poor solution concentration

Figure 8 shows certain generator temperature contours for obtaining COP between 0.3 and 0.4. based on Figure 7, We see that assumption ranges for solar system which is 120-150 °C, the assumption concentration range matches with generator temperature between 130-140 °C.

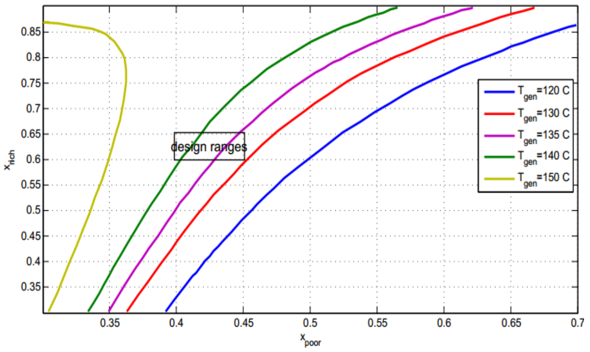

Figure 8. generator temperature contour vs concentrations in appropriate COP range

Another outstanding parameter must be considered is the evaporator temperature. Figure 9 shows COP contours against the evaporator temperature in the generator temperature. In constant generator temperature ranges, if the evaporator temperature is increased, COP will be increased.

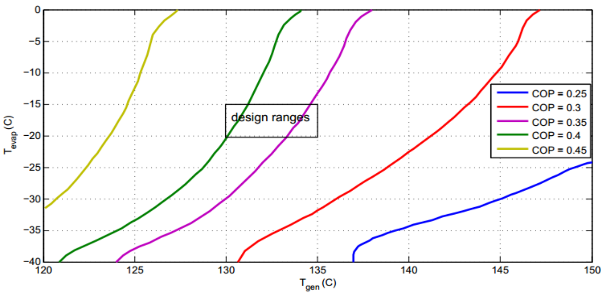

Figure 9. COP contour vs outstanding cycle temperature in appropriate generator temperature

4. Conclusions

A thermodynamic model has been developed to predict the performance of the diffusion absorption refrigeration system for various generator temperatures and concentrations of the refrigerant (ammonia) in the rich solution of ammonia-water solution. COP of absorption cycle is highly dependent on generator temperature and evaporator. Thus, in order to gain high COP, all of cycle components must be in optimum condition. The results show that according to assumptions, it is plausible to gain 0.4 for COP theoretically.

Nomenclature

A	area
c	specific heat of a fluid
COP	coefficient of performance
g	Acceleration due to gravity (m/s^2)
h	specific enthalpy (kj/kg)
$h_{i,o}$	heat transfer coefficient ($\frac{W}{m^2.K}$)
$\dot{m}$	mass flow (kg/s)
P	pressure (kPa)
q	specific heat (kj/kg)
Q	heat (kW)
T	temperature (C)
u	specific internal energy (kj/kg)
ρ	density (kg/m^3)
ε	effectiveness (heat exchanger)

Subscript

A	absorber
abs	absorber
aux	auxiliary gas
c	condenser
cond	condenser
E	evaporator
evap	evaporator
G	generator
HX	Heat Exchanger
min	minimum
max	maximum
Mch	Mixing chamber
R	rectifier
sys	system

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