Construction and performance study of a solar - powered hybrid cooling system in Iraq

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Abstract

The systems cooling hybrid solar uses solar collector to convert solar energy into the source of heat for roasting Refrigerant outside of the compressor and this process helps in the transformation of Refrigerant from the gas to a liquid state in two-thirds the top of the condenser instead of two-thirds the bottom of the condenser as in Conventional cooling systems and this in turn reduces the energy necessary to lead the process of cooling. The system cooling hybrid use with a capacity of 1 ton and Refrigerant type R22 and the value of current drawn by the system limits (3.9-4.2A), the same value of electric current calculated by the system are Conventional within this atmosphere of Iraq, and after taking different readings of the temperatures and pressure to several points in the system's found that the Refrigerant when it comes out of the compressor, it loses part of the temperature of the water in the solar collector through a heat exchanger while the literature published in accordance with the manufacturers that the solar collector, a kind of vacuum tubes contributes to raise the pressure and temperature of the fluid cooler to reduce the consumption of energy spent on compressor. Therefore, the system described by the current not fit for domestic use within the Iraqi environmental conditions.

Key words
Solar energy,
Cooling system,
Solar collector,
Compression cooling cycle.

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تقييم أداء منظومة تبريد هجينة تعمل بالطاقة الشمسية وفق الأجواء العراقية

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الخلاصة

في منظومات التبريد ألهجينه العاملة بالطاقة الشمسية تستخدم مجمع شمسي لتحويل الطاقة الشمسية إلى مصدر حرارة لتحميص مائع التثليج الخارج من الضاغط وهذه العملية تساعد في تحول مائع التثليج من الحالة الغازية إلى الحالة السائلة في الثلثين الأعلى من المكثف بدلا من الثلثين السفلي من المكثف كما في منظومات التبريد التقليدية وهذا بدوره يقلل من الطاقة الضرورية لقياده عمليه التبريـــــــــد ،تم استخدام منظومة تبريد هجينه بسعة 1 طن ولمائع التبريد نوع R22 وكانت قيمه التيار المسحوب من قبل المنــــــظومة بحــــدود (3.9-4.2A) وهو نفس قيمه التيار المحسوب من قبل منظومة تقليدية ضمن هذه الأجواء للعراق، وبعد اخذ قراءات مختلفة لدرجات الحرارة والضغط لعده نقاط في المنظومة وجد إن مائع التثليج عندما يخرج من الضاغط فأنه يفقد جزء من حرارته إلى الماء الموجود في المجمع الشمسي عن طريق المبادل الحراري في حين إن الأدبيات المنشورة وفق الشركات المصنعة إن المجمع الشمسي وهو من النوع المفرغ الأنابيب يساهم برفع الضغط ودرجة الحرارة لمائع التثليج وذلك لتقليل استهلاك الطاقة المصروفة على الضاغط. لذلك فأن المنظومة على وصفها الحالي لاتتناسب للاستخدام المنزلي ضمن الظروف البيئية العراقية.

Introduction

Cooling is defined as the process of withdrawing heat load generated in the space and providing suitable temperature and humidity within the space. Nowadays, solar cooling technology is considered as one of the most important solar energy applications [1]. Especially it is clean and renewable energy and doesn't need high–tech to get it .as well as it is easy to install, whether in the houses or factories, that gives it special importance with pollution increment. Solar cooling is defined as that system designed to use solar thermal complexes to drive the cooling process in the space we want to streamline or reduce the amount of electricity consumed in refrigeration [2]. Cooling using solar thermal compound at the present time has become one of the most efficient cooling systems in the market that lead to rationalization in the consumption of electricity significantly, leading to the recovery of the costs of purchasing the system within a short period [3]. Conradie and Kröger (1991) investigated and compared two methods of enhancing the thermal performance of an air-cooled condenser: Deluging the air-side surface of the aircooled condenser with water, enabling both sensible and latent heat transfer, and the adiabatic spray cooling of air entering the air-cooled condenser [4]. Investigating adiabatic enhancement of air-cooled power plants in California, Maulbetsch and DiFilippo (2003) conducted tests on various low-pressure nozzles and the arrangement of the nozzles [5]. Johan Adam (2008) evaluates the performance characteristics of a power plant incorporating a steam turbine and a direct air-cooled dry/wet condenser operating at different ambient temperatures [6]. Chaobin (2012) enhanced the cycle performance of a solar-powered air conditioner and showed that the proposed hybrid ejector cycle could operate during both the heating and cooling seasons and would provide energy savings [7]. Cooling system contains the same basic components in the conventional system of compressor, condenser and evaporator that form the closed cooling cycle component, which follow fluid compression cycle to absorb heat from sink and push it to source by means of compressor, these fluids called cooling media as shown in Fig.1 But addition of a specials solar collector between the compressor and condenser and fixed on the surface as shown in Fig. 2 Hybrid solar conditioning system operates a high efficiency compressor designed to circulate refrigerant to the solar collector - glass evacuated tubes. The last heats the refrigerant via heat exchanger existing inside the tank to higher temperatures reducing the power consumed by the compressor.

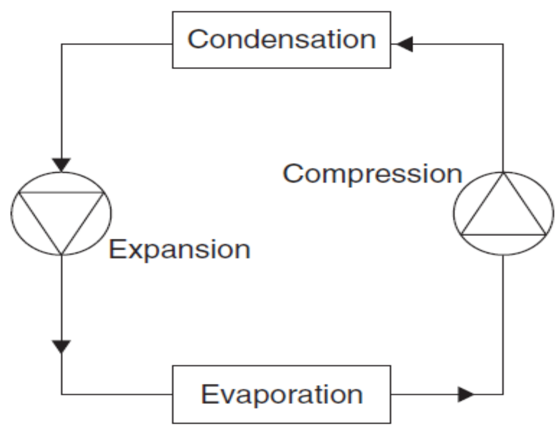

Fig.1: Conventional cooling cycle [8].

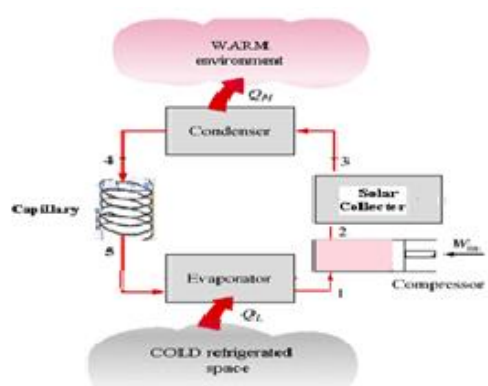

Fig. 2: Hybrid cooling cycle [9].

For comparison ,the conventional air conditioning system uses electrically operated compressor to compress and heat the refrigerant up to 170 C^{o} .then gas moves towards the external condensing coils .where turns into liquid phase [10] .typically this takes place at the last third of the condensing coil . from there passes through an expansion valve which causes drop in the pressure and temperature of the refrigerant where it enters the evaporator then the heat of the air present in space and passing through the internal coil of the air conditioner is absorbed . to return into the gaseous phase and enters the compressor to restart the whole cycle again .while in the hybrid solar conditioner which uses the costless solar energy the principal task is to heat the refrigerant to a temperature higher than the one produced by compressor in conventional cooling cycle [11]. Fixing the solar collector leads to more efficient performance of the refrigerant with no need to rotaries or any extra engines. This increases the gas ability for turning into liquid phase faster and decreases the power required by composer significantly. Where gas now is condensed to return into saturated liquid at the first third of the condensing coil not at the last third. Therefore the refrigerant approaches the internal coil. Almost will be totally in liquid phase. That results in more efficiency refrigerant of more ability to absorb heat. That makes it 6 – 5 degree cooler at the internal coil, leading to transferring the cooler and drier air to the building.

Real Compression Cooling Cycle

The Real compression cooling cycle is less efficiency than ideal cycle as shown in Fig.3 because the last neglects pressure drop caused by friction between fluid and pipes at the condenser and the evaporator .also. sub cooling of the fluid and super heating vapor are two important to insure that the out refrigerant from condenser towards the expansion valve is totally in liquid phase and contains no vapor at all, also to ensure the absence of any liquid droplet with vapor out from the evaporator towards the compressor. In addition to that, the cooling vapor undergoes some super heating at the pipe connecting between evaporator and the entrance of the compressor .As shown at the points 6 to a before the super heated vapor to enter the compressor there should be a pressure drop through suction valve from a to b, where the compression will be at the compressor cylinders at the point b, mostly the inner surface of the cylinder is hotter than the vapor entering the cylinder which causes the vapor to be more super heated when it is in contact with inner surface of the cylinder from b to 1 before compression. Analyzing the real cycle doesn't differ from analyzing the previous cycle and requires knowing the different cases and the ongoing process, and when the pressure drop rates at the condenser, evaporator and through the compressor valves. furthermore the amount of super heating and cooling at the pipes connecting the compressor with evaporator and condenser respectively then we can identify the different cases on the (pressure Vs enthalpy) chart and finding out enthalpy values to calculate all the variables of the cycle.

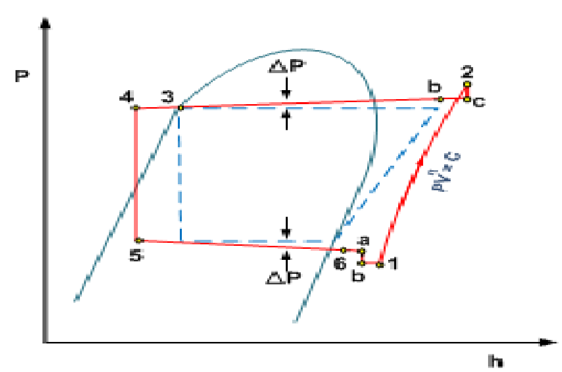

Fig.3: p-h diagram of real compression cycle[12].

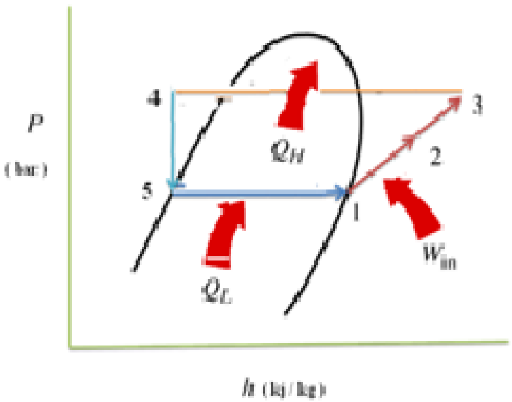

Fig.4: p-h diagram of hybrid compression [12].

Hybrid Compression Cooling Cycle

It basically consist of five processes as shown in Fig. 4

- Process (1 ⟶ 2), it takes place at the compressor . Here the refrigerant vapor is compressed at high temperature and high pressure.
- Process (2 ⟶ 3), it takes place at the solar collector. Here the temperature refrigerant coming from the compressor is increased up to temperature and pressure suitable to enter the condenser.
- Process (3 ⟶ 4), it takes place at the condenser .here the refrigerant vapor cooled to turn in a lower temperature liquid.
- Process (4 ⟶ 5), it takes place at the capillary tube. Here the refrigerant turns from high temperature high pressure liquid into low temperature low pressure liquid by choking.
- Process (5 ⟶ 1), it takes place at the evaporator. Here the room is cooled by mean of heat exchange. Where the evaporator absorbs the heat from the room to the saturated liquid refrigerant turning the last into gas of low pressure and low temperature [12].

Experimental Part

Description of System Operating

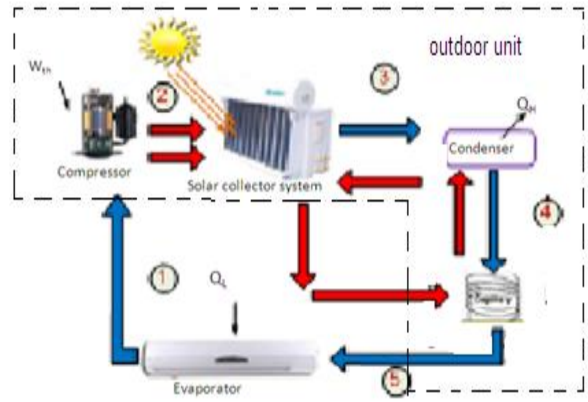

Fig. 5: diagram for hybrid cooling system [13].

Hybrid cooling system (solar and electrical power) consists of two main parts:

1- Outdoor unit, which consists of solar collector, condenser, compressor, four ways valve, stop valve and the thermostat inside the solar collector.
2- Indoor unit consists of evaporator, fan and thermostat.

The system shown in Fig.5 operates as following: The compressor operates after it is provided with electrical power, from electric grid that increases temperature and pressure of the refrigerant vapor coming from the evaporator and pumps it to the solar collector which increases the refrigerant temperature and pressure then the refrigerant vapor enters the condenser hence a heat exchange between the refrigerant vapor and the ambient takes place gradually and convert the refrigerant from gas into liquid. Then refrigerant liquid temperature and pressure are reduced inside the capillary tubes which are parts of the condenser pipes while maintaining the enthalpy so that the temperature and pressure reaches the evaporator temperature and pressure. Then refrigerant liquid enters the evaporator and heat exchange process take place between evaporator and the room (the space to be cooled) takes place turning the refrigerant into vapor gradually that causes the heat load to be absorbed from the room to maintain the designed comfortable conditions - inside the room - of temperature and humidity. Finally refrigerant vapor enters the compressor and the cycle will be restarting again.

System Components

The hybrid cooling system - as shown in the chart - consists of two main parts:

1- Outdoor unit: consists of the following main parts:

A- Compressor: increases the temperature and pressure of the refrigerant vapor coming from the evaporator and forwards it to the solar collector. it is the rotary type compressor. Operates on electrical power form national grid. Input power (600 - 860) Watts. Operating voltage (220V - 50 Hz-1 PH). Estimated current (2.7 - 3.8) Amp.

B- Solar Collector: Increases the temperature and pressure of the refrigerant vapor that comes from compressor. The type of collector is evacuated tube solar collector. Contains (10) evacuated tubes. Contains cylindrical water tank with a spiral upper coil fixed inside, through which refrigerant vapor passes. The collector is oriented towards south as shown in Fig.6.

C- Condenser: Ejects the heat from refrigerant vapor that is coming from solar collector to the external ambient. Inside contains a group of spiral pipes work on temperature and pressure of refrigerant turning it into liquid phase.

D- Fan: Draws the air from the space and drives it towards the condenser to increase the heat exchange between condenser and the ambient space. It is axial fan.

E- Controlling devices: a-four ways valve (V-101):-controls the refrigerant flow. b-stop valve:- closes the cycle path to prevent refrigerant to reach the evaporator until the temperature at the solar collector is risen.

2- Indoor unit: consists of the following parts:

A- Evaporator: performs the heat exchange between refrigerant passing throw spiral pipes of the evaporator and the space to be cooled. It is dry type evaporator.

B- Fan: increases the heat exchange by drawing the air inside the room towards evaporator pipes that contain the refrigerant. It is centrifugal fan. Air circulation rate is 520 m^3 /h.

C- Controlling devises: Thermostat to sense and control the temperature in the room. It senses the temperature inside the room and compares it to the temperature set by the remote control .In case the temperature inside the room approaches the set temperature then the thermostat sends an electrical signal to stop the compressor.

D- Air filter: Purifies the air in the room from dust and bacteria.

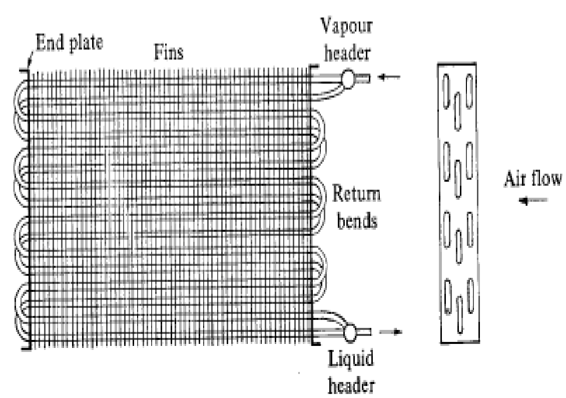

Fig.7: Element of condenser [13].

Experimental setup and procedure

Hybrid cooling system- working by solar energy used- is of type Atlantis trade mark with capacity of one ton. These are the technical specifications of the system:-

1-wall mount split, 2- Model SK 1.5 W, 3- Power supply 230 V 50 Hz 1PH, 4- Input power 600- 869 W, 5- Rated current 2.7 -3-9 Amp, 6- Cooling capacity 12000 Btu/h.

7- Circulating blast volume = 520 m^3/h, 8- Refrigerant: R22, 9- Net weight 38 Kg.

At the time of installation of the system the solar collector tank is filled up with distillery water and left until next day to increase water temperature in the solar collector then connecting the sensors and gauges for the temperature and pressure for the following:-

1- Temperature and pressure of the gas entering the compressor.

2- Temperature and pressure of the gas out from the compressor.

3- Temperature and pressure of the gas out from the solar collector.

4- Temperature and pressure of the gas out from the condenser.

5- Temperature of the water in the solar collector.

6- Ambient temperature

At all of the previous cases it is observed that the temperature of the fluid out from the compressor is higher than the temperature from the temperature in solar collector tank resulting in increment in the water temperature and decrease in the temperature of the fluid out from the solar collector as shown in Fig. 8.

Fig.8: Description connects of hybrid solar collector.

Results and Discussion

A period of three clear sky days (27^{th}, 28^{th}, 29^{th} Sep 2011) have been selected for measuring all necessary data for analysis of the performance of the system by using solar collector filled with water. A typical data obtained in these days are showing in Tables (1,2 and 3). The R22 P-h charts describing the hybrid solar collector are shown in Figs. 9, 10 and 11. Which figures show the ambient temperature measured at the site during the test hours for the four days of the experimental part, higher temperatures were observed during the day time occurring between 12:30 pm and 13:30 pm. The total solar radiation was measured during the test period exhibited, higher values of total solar radiation between 11:30 am and 12:30 pm. A period of two clear sky days (5^{th} and 6^{th} Oct) has been selected for measuring all required data, as was mentioned previously for analysis of the performance of the hybrid solar collector without water in tubes as shown in Tables 4 and 5. The required data foR describing the R22 P-h chart are demonstrated in Figs. 12 and 13. that the performance of the system is high, the collector's performance is also good for October days, although the solar radiation and ambient temperature is lower than those of the October days.

Table 1: Hybrid solar collector with water 27/9.

Current A	Amb Temp C^o	Water Temp C^o	Cond out		Collector out		Comp out		Comp in		Time
			P psi	T C^o	P psi	T C^o	P psi	T C^o	P psi	T C^o	
4	38.7	55.3	95	30.8	190	47.3	205	57.8	54	27.1	8:00
4.1	41.3	57.3	95	28.2	195	50.6	215	75.4	56	27.2	8 :30
4.3	45	57.8	100	32	210	56.6	220	77	56	30.2	9 :00
4.3	45.4	55.2	100	34.6	215	61	235	75	58	33.1	9 :30
4.4	46.5	53.4	105	38.6	220	64.9	235	76.4	60	30.6	10 :00
4.5	47.8	51.3	105	41.7	225	69.7	240	78	62	32.9	10 : 30
4.4	48.2	49.8	105	42.7	225	72.6	235	77.5	56	32.1	11 : 00
4.4	48.2	50.5	105	43.3	225	73.7	235	77.4	56	31.9	11 : 30
4.5	49	49.4	105	44.7	230	75.2	240	78	56	32.2	12 : 00

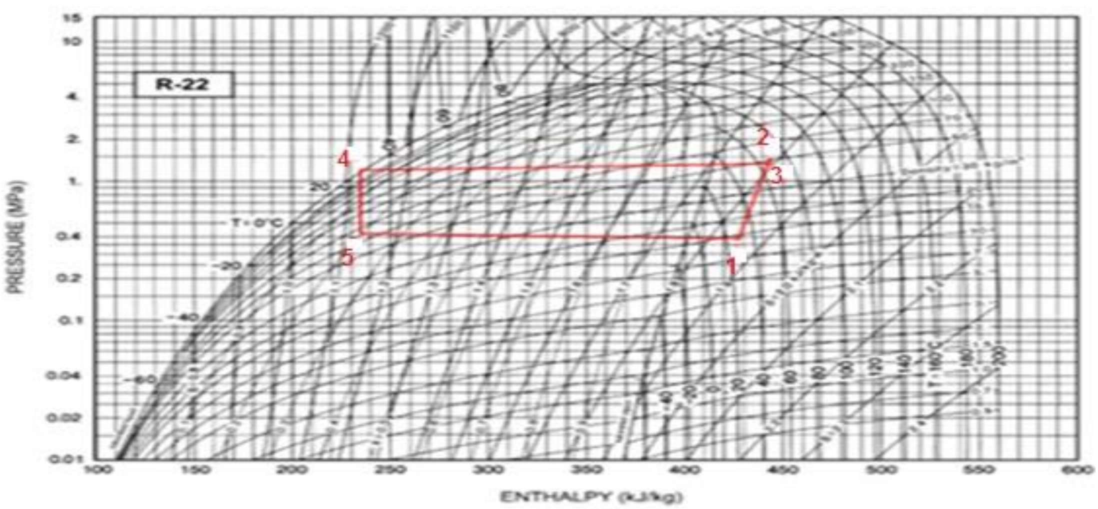

Fig. 9 P-h chart with water 27/9

Table 2: Hybrid solar collector with water 28/9.

Current A	Amb Temp C^o	Water Temp C^o	Evap in		Collector out		Comp out		Comp in		Time
			P Psi	T C^o	P psi	T C^o	P psi	T C^o	P psi	T C^o	
0	28.1	46.6	125	31.3	130	32	135	32.6	120	31.3	7:45
3.8	30.3	49.8	90	29.4	175	48.4	195	56.2	54	28.3	8 :15
3.9	34.7	56.2	95	31	180	53.2	200	58.4	54	29.9	8 : 45
4.	32.8	59.6	95	32.3	185	56.3	205	59.5	54	30.9	9 :15
4.1	36	61.6	95	33.1	190	58	210	60.1	54	31.2	9 : 45
4.2	37.2	62.2	95	34.6	195	60.3	215	62	54	32.5	10 : 15
4.2	41	59.7	100	36.9	210	63.2	220	65.2	54	34.5	10 : 45
4.2	34.9	58.1	100	38.9	215	65.9	225	66.1	58	36.6	11 : 15
4.2	42.2	50.9	100	41.9	215	69.6	225	69.8	58	39.4	11 : 45
4.2	42.3	51.4	100	42.1	215	70.3	230	70.4	58	39.6	12 :15
4.2	40.9	51.8	100	42.7	215	70.7	230	70.6	58	39.4	12 :45

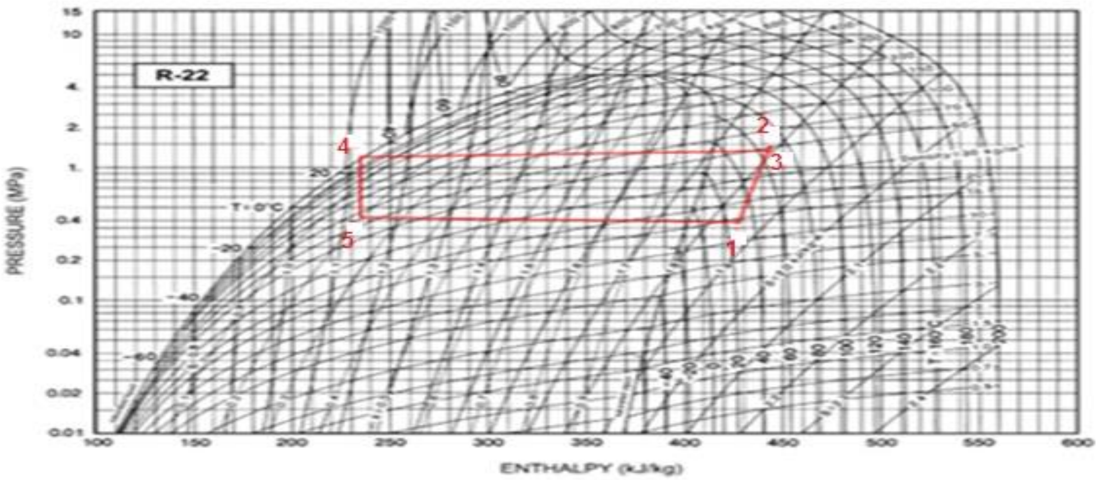

Fig.10: P-h chart with water 28/9.

Table 3: Hybrid solar collector with water 29/9.

Current A	Amb Temp C°	Temp Water C°	Evap in		Collector out		Comp out		Comp in		Time
			P psi	T C°	P Psi	T C°	P Psi	T C°	P psi	T C°	
0	27.3	47.6	125	30.8	125	31.1	130	31.2	120	30.7	7:45
3.9	31.4	53.1	90	28.1	175	46.9	190	54.5	52	25.5	8 :15
3.9	32.8	58.7	90	30.3	175	52.4	195	57.2	52	25.5	8 : 45
3.9	31	62.3	95	32	180	55.7	200	59.4	54	26.9	9 :15
3.9	34.5	65.4	95	33.3	185	58.4	200	61.1	54	27.5	9 : 45
4.0	35.6	67.5	95	34.3	190	59.7	205	60.9	54	28.2	10 : 15
4.1	36	68.4	95	36.2	195	61.1	210	62	56	29.5	10 : 45
4.1	33.1	70.2	95	35.5	200	62.1	215	62.7	56	29	11 : 15
4.2	39.2	70.9	95	36.7	205	63.6	220	64.1	56	29.9	11 : 45
4.2	43.9	71	100	36.5	210	64.3	230	64.9	54	30.1	12 :15
4.3	44	71.3	100	36.7	215	64.8	230	65	56	30.9	12 :45

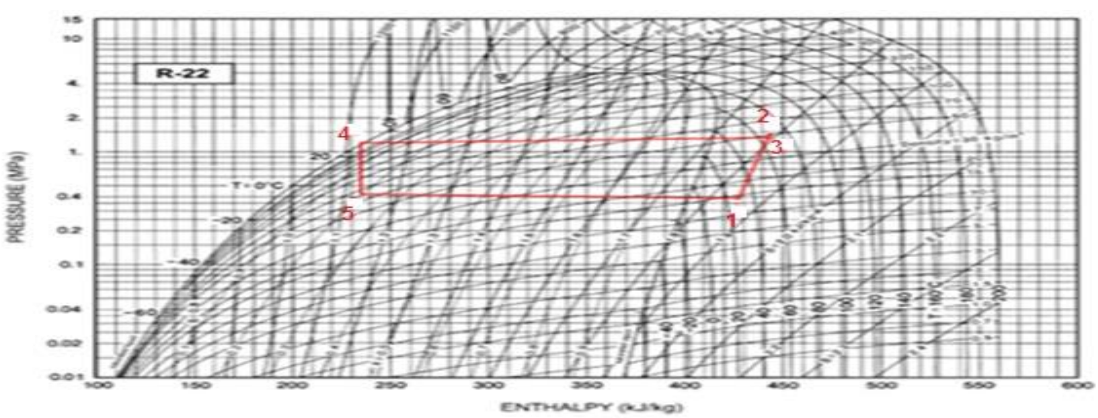

Fig. 11: P-h chart with water 29/9.

Table 4: Hybrid solar collector without water 5/10.

Current A	Amb Temp C°	Temp Water C°	Evap in		Collector out		Comp out		Comp in		Time
			P psi	T C°	P psi	T C°	P psi	T C°	P psi	T C°	
0	27.3	0	110	28	115	29.1	120	29.8	106	28.9	8:45
3.45	30	0	85	28.8	165	51.9	180	52.9	50	17.2	9:15
3.6	31.9	0	90	31.6	175	55.9	190	56.3	52	17.6	9: 45
3.65	30.5	0	90	32.7	175	57.6	190	56.4	52	17.7	10 :15
3.7	31.6	0	90	32	175	57.1	190	57.3	52	17.9	10: 45
3.7	33.1	0	90	32.2	185	56.6	195	55.6	50	16.9	11: 15
3.7	34.2	0	90	32.7	185	56.7	195	55.7	50	17.2	11: 45
3.7	30	0	90	31.5	185	56.9	195	55.8	50	16.7	12: 15
3.7	32.6	0	90	33.3	190	58.4	195	56.5	50	18	12: 45
3.7	31.2	0	90	33.3	190	57.7	195	56.3	50	18.2	1 :15
3.7	34.2	0	90	32.9	190	58.1	200	56.3	50	20.9	1 :45

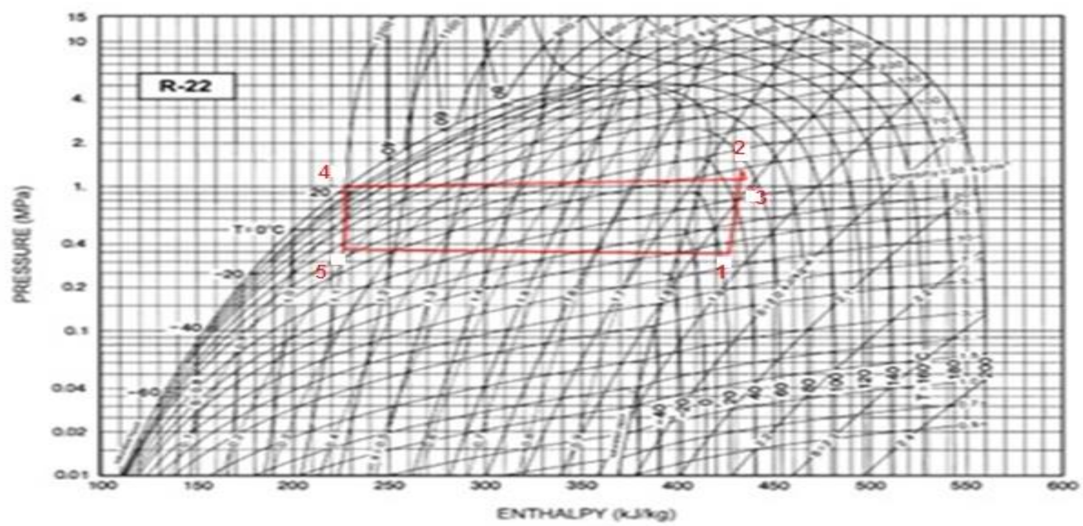

Fig. 12: P-h chart without water 5/10.

Table 5: Hybrid solar collector without water 6/10.

Current A	Amb Temp C°	Temp Water C°	Evap in		Collector Out		Comp out		Comp in		Time
			P psi	T C°	P Psi	T C°	P psi	T C°	P psi	T C°	
0	25.2	0	110	27.4	115	27.8	115	28.9	102	27.6	8:45
3.63	27.5	0	85	26.9	160	49.2	180	50.2	50	23.4	9:15
3.68	28.6	0	85	27.3	165	50.4	180	50.2	50	23.6	9: 45
3.75	32.8	0	85	28.9	165	52.5	185	51.9	50	25.1	10 :15
3.82	33.5	0	85	29.7	175	54.3	190	53.4	50	25.8	10: 45
3.83	30.2	0	90	30.5	175	54.9	195	53.5	50	26	11: 15
3.8	30.7	0	90	30.7	175	55.2	195	54.4	50	25.7	11: 45
3.91	31.4	0	90	31.5	180	56	195	54.9	50	26.1	12: 15
3.91	34.5	0	90	32.2	180	57.7	195	57.4	50	27	12: 45
3.9	31.9	0	90	32.3	180	58	195	56.9	50	27	1 :15
4	37.3	0	90	32.2	195	59	215	57.7	52	27.2	1 :45

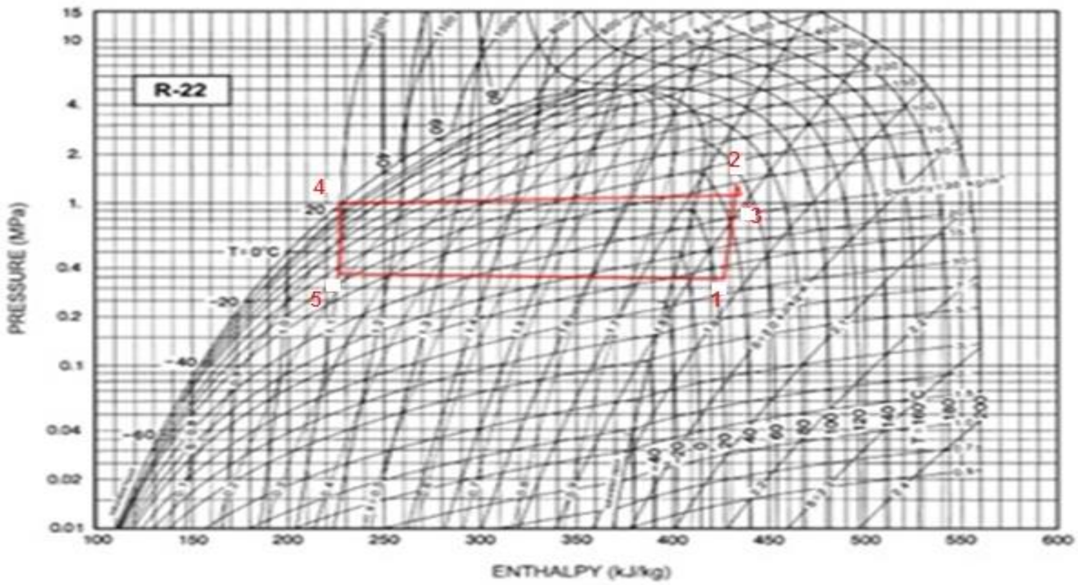

Fig.13: P-h chart without water 10/6.

Conclusions

From all the previous records it has been concluded that the solar collector and the hybrid cooling system does not rise the refrigerant temperature. Whereas the fluid rises the solar collector temperature. where refrigerant loses a part of its heat to the water in the tank via heat exchanger also it is noticed that the fluid pressure has been decreased after leaving the solar collector (Figs. 9,10 , and11) it also noticeable that in case of no water is in solar collector then the system behaves similar to a conventional cooling system as it is shown in p-h chart (Figs. 12 and 13). The experimental result shows the average thermal efficiency which is fairly acceptable assessment results of a collector locally.

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