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Investigation of the Performance of a Solar Powered Adsorption Heat Pipe

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ABSTRACT

An adsorption heat pipe was designed and built from a stainless steel tube of 32 mm outer diameter, 30 mm inner diameter and 1000 mm long, the inner surface of the tube was coated by 10 mm thickness of active carbon, which was assumed to be the adsorbent, while the adsorbent was assumed to be the methanol, or acetone. The adsorption heat pipe consist of three zones, namely adsorption/ desorption, adiabatic and evaporation/condensation zones. Electrical heater with variables capacity is used to heat up the unit generator during desorption process, water was used to cool the condenser, while air was used to cool the generator. Two types of adsorption pair are used, namely active carbon-methanol and active carbon-acetone. The effect of heat input to the generator on the heat pipe surface temperature and evaporator temperature are studied. The results showed that the adsorption heat pipe can work at a relatively low temperature namely 70-100 ^{o}C, the time required for cooling process in the range of 18 to 24 minutes, and activated carbon – Acetone pair gave a good behavior for the heat pipe due to the short cycle– time compared with that for activated carbon – Methanol

Keywords: - Adsorption, Adsorbent, Refrigeration; Heat pump,Adsorption Heat Pipe.

استقصاء اداء انبوب حراري امتزازي يعمل بطاقة الشمس

الخلاصة

في هذا البحث تم تصميم و بناء انبوب حراري امدزازي , استخدم انبوب مصنوع من الفولاذ غير القابل للصداء بقطر خارجي مقداره 32 ملم و قطر داخلي مقداره 30 ملم، في حين ان طول الانبوب كان يساوي 1000 ملم. وضعت بطانه من الكاربون المنشط بسمك 10 ملم على السطح الداخلي

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للأنبوب المعدني. و استخدم زوجان مازان هما الكاربون المنشط- الميثانول و الكاربون المنشط- الاسيتون. يتكون الانبوب الحراري من ثلاثة مناطق هي منطقة الامتزاز-التحرير، والمنطقة المتعادله حراريا و منطقة المكثف-المبخر. استخدم مسخن كهربائي بسعات مختلفة لتمثيل الحرارة المضافة الى مولد البخار، واستخدم الماء لتبريد المكثف، في حين المولد تم تبريده بواسطة الهواء الخارجي. تمت دراسة تاثير الحمل الحراري المضاف الى المولد على كل من درجة حرارة سطح الانبوب و درجة حرترة المبخر. بينت النتائج العملية ان الانبوب الحراري يمكن ان يعمل عند درجات حرارة منخفضة للمدى 70 الى 100 درجة مئوية، و كان الوقت اللازم لاتمام عملية التبخر في المبخر يتراوح من 18 الى 24 دقيقة، وبينت النتائج ايضا ان زوج الامدزاز الكاربون المنشط- الاسيتون يحتاج الى وقت اقل لاتمام الدورة مقارنة بذلك الذي يستخدم زوج الامدزاز الكاربون المنشط الميثانول.

INTRODUCTION

Vapour compression systems still dominate in almost application areas. This is because that there are certain disadvantages which hinder adsorption systems from real mass production commercialization. They are: long adsorption/desorption time, small refrigeration capacity per unit mass of adsorbent, i.e., low Specific Cooling Power (SCP), which leads to a bulky system and low Coefficient of Performance (COP) of the system [1].Therefore the novel technologies for adsorption refrigeration have been extensively studied in academic as well as industry sector. Large amount of patents have been filed in different countries around the world, which lead to substantial improvement on system COP and SCP, and novel applications in various area. Adsorption heat pipe technologies is a useful tool in improving the heat transfer and simplify structure in system level, further study should be conducted to utilize this technology with increased reliability and lower initial investment [1]. Guilleminot, J.J., et al. [2] 1993studied a consolidated composite compound made from a mixture of zeolite and metallic foam. The compound produced from zeolite and copper foam had a thermal conductivity of 8.0 W/mK, which was 22 times higher than that of consolidated zeolite. Vasiliev, L.L., [3] 2001 has designed an adsorption system that could be powered by solar energy or electricity. Heat pipes were used in the heat transfer fluid and refrigerant circuits. Dr.Critoph [4] 2001 described a rotary thermal regenerative adsorption system, which has a number of adsorbent modules (tubular adsorption module) circumferentially about a rotational axis partly within a toroid conduit.

Nun˜ez, T., et al. [5]2004 developed and tested a silica gel-water adsorption chiller with nominal cooling power of 3.5 kW. It had two adsorbers filled, each one, with 35 kg of adsorbent. The chiller operated at generation temperatures between 75 and 95 °C. Liu, Y.L., et al. [6]2005 Developed an adsorption water chiller which was introduced and tested. In the new adsorption refrigeration system, there are no refrigerant valves.

Based on the principle of heat pipe, a novel silica gel-water adsorption chiller has been designed in Shanghai Jiao Tong University (SJTU) in China [7] 2005 and [8] 2005. There are three vacuum chambers in adsorption chillier two adsorption /desorption (or evaporation /condensation) vacuum chambers and one heat pipe working vacuum chamber as the evaporator. Lu, Z.S., et al.[9]2005, and Wang, L.W.[10] 2006 , disclosed a calcium chloride active carbon compound adsorbent. The adsorbent can be divided into granular and consolidated type. The component and weight percentage of the granular type was calcium chloride 60%-78%, active carbon 22%-40%. The consolidated type: calcium chloride 49%-60.2%, active carbon 17.2%-32.7%, water 12.2%-15.1%, cement 6.1%-7.5%. Wang, R.Z., et al. [11] 2006 had studied a solar composite energy system based on solid adsorption refrigerating machine for solar energy application and energy conservation in building. This system includes solar collection system, solar hot water supply system, and solar floor heating system, solar air-conditioning system, solar natural ventilation system and control system.

EXPERIMENTAL WORK

The adsorption heat pipe consists of the followings:

Stainless steel tube: a stainless steel tube of outer diameter of 32 mm, 30 mm inner diameter, and 1000 mm long, is used as the adsorption heat pipe body. Both ends of the steel pipe are closed by flanges; one of the two flanges is supplied by a valve that used to charge the heat pipe by the working fluid. the steel pipe is divided into three zones, the first zone represent the adsorbing desorbing zone of 500 mm length, that contain the active carbon materials, the second zone made of Perspex of 180 mm length, which called the adiabatic zone, while the third zone is the condensing/evaporating zone, figures (1) and (2) show a section in the adsorption heat pipe and the flanges, respectively.

1. Adsorbent; a consolidated composite adsorbent was selected to form the generator structure. Calcium chloride was supplied are crushed to powder in average particular diameter of (50-90) μm. The obtained powder is then mixed with granular activated carbon and cement with different mass ratio of active carbon to calcium and cement were made namely, 1:1:1, 2:1:1, 4:1:1, 5:1:1, 1:2:1, and 6:4:1 and a lot of water. The last sample (6:4:1) was selected, after many test procedures and showed that another mass ratio suffered from swelling phenomena to make the adsorbent bed. Figure (3) shows the tested samples. The outer diameter of the sample is about 30 mm, while the inner diameter is about 10 mm. many consolidated composite adsorbent parts of 127 g weight were used to make the adsorbent layer inside the steel tube.
2. Working fluid: the adsorption heat pipe is charged by 38 g of methanol or acetone, they are used as refrigerant that transfer heat from condensing/evaporating zone to adsorbing/desorbing zone by phase change.
3. System setup: the adsorbent heat pipe were supplied with many accessories, namely, electrical heater that used to heat the desorber, it will called a generator. A variable AC transformer (Variac) with output voltage of 0 to220V, water tank and water pump, that used to cool the condenser during desorption process, and finally a fan, that used to cool the generator during adsorption process, the unit set up is shown in figures (4) and (5).
4. Measurements and instruments: ten thermocouples of type K, distributed at 10 cm distance, along the heat pipe surface, were used to measure the surface temperature,

an additional thermocouple is used to measure the ambient temperature, a probe is inserted through the heat pipe to measure the temperature of methanol vapour, and condenser cooling water temperature is measured by two thermocouples placed at the jacket water inlet and outlet tubes. All thermocouples were connected to a compatible selector switch and then they were connected to a digital thermometer. Coolant water flow rate was measured by flow meter.

5. Sequence work of adsorption heat pipe: Figures (6) and (7) show the operation sequence of the adsorption heat pipe. Desorption process starts when powered the electrical heater, as shown in figure 6-A, When the desorption zone, generator, receives heat, its temperature and pressure increased, until they reached the condenser pressure corresponding to condenser temperature, process 1-2 of figure (7), then the methanol desorbs from active carbon, vapour methanol flows to condensing zone, where heat is rejected and methanol condenses at constant pressure, process 2-3 of figure(7). When all methanol desorbs from generator, the electrical heater switched OFF, and the generator is cooled by ambient air,as shown in figure 6-B, due to cooling process, both pressure and temperature of liquid methanol falls from generator pressure to evaporator pressure, process 3-4 of figure (7). As the pressure reaches evaporator pressure, liquid methanol boils at low temperature due to absorb heat from evaporator enclose, changing to vapour and flows to adsorption zone process 4-1 of figure (7), and adsorbed by active carbon there. The success of the unit is that when the initial pressure for a selected purpose was returns back to its initial value after completing one adsorption cycle. The initial pressure of the adsorption heat pipe were chosen to be 10 kPa when methanol is used as a refrigerant, and 20.5 kPa when acetone is used as a refrigerant, both pressures mentioned above give evaporator temperature of about 16^{o}C.
6. Key variables: the followings variables were studied in this work, namely heat input to the generator, type adsorption pair, namely active carbon-methanol and active carbon-acetone. for all variables mentioned above the effect of heat input to the generator on the pipe surface temperature, evaporator temperature and the performance of heat pipe were studied.

RESULTS AND DISCUSSIONS

Figure (8) shows the variation of selected node temperatures, and average generator temperature (Tg which represent the average values of generator surface temperature), and working pressure with the time, for input power of 60W, ambient temperature of 26 ^{o}C and using methanol as a working fluid. It can be seen from the figure that, the generator pressure was started from about 10 kPa and increases to about 18 kPa, and remains constant, for a period of time, due to condensation of methanol in the evaporator section. When all the methanol condensate, the generator is cooled by ambient air, and the pressure falls to the initial pressure of 10 kPa, which maintain a saturated temperature of about (17.5 ^{o}C). Also it can be seen from the figure that the generator surface temperature reaches a maximum average value of about 98^{o}C, while the temperature of the condenser was in the range of 38 ^{o}C.

Figure 9 shows the variation of selected node temperatures and working pressure with time when methanol was used as working fluid at 22 ^{o}C ambient temperature and 67.2W power input to the generator. It can be seen from the figure that, the unit pressure was increase to about 15 kPa, the relatively high evaporator temperature at 20 ^{o}C at completed cycle is due to the low heating time compared with that, when the input power was 60W, and due to the low initial temperature which is about 20 ^{o}C the desorption process of methanol from generator is not complete.

Figure 10 shows the variation of selected node temperatures and pipe working pressure, when the input power is 74W, when ambient temperature is 30^{o}C, and the methanol is used as working substance. The heating time is about 40 minutes. It can be seen from the figure that, the average generator temperature is 105^{o}C, and the unit pressure started from initial value of 10 kPa and increases gradually until it reaches the high level of about 2.5 kPa, corresponding to ambient temperature. as generator unit was cooled the unit pressure falls rabidly to its initial value, this lead the liquid methanol to boil at about 17 ^{o}C, producing the cooling effect. The time required to the methanol to change its phase from liquid to vapour is about 18 minutes, while the whole cycle time to complete on cycle is about 58 minutes.

Figures (11,12 and 13) are showing the variation of selected node temperatures unit pressure, when acetone is used as working fluid, input power was 60, 67.2 and 70 kW respectively. It can be seen from the figure that, the initial working pressure for acetone was about 20kPa, compared with 10 kPa for methanol, which means that acetone has a low boiling point compared with that for methanol, Generally the behavior of the adsorption heat pipe working with activated carbon- methanol was the same as that for activated carbon-acetone, the difference was only with working pressure and temperature, the minimum evaporator temperature is about 17.5 ^{o}C, and the cycle time is about 50 min, which is less than that for the heat pipe cycle working on activated carbon-methanol.

Figures (14) shows a complete cycle of adsorption desorption processes, when the heat input is 60 W, ambient temperature of 26^{o}C, and the adsorption pair is active carbon-acetone. It can be seen from the figure that, the cycle started at point A from initial temperature and pressure of 26 ^{o}C and 10 kPa respectively. As electrical heater turn ON, both generator temperature and pressure are increased gradually until it reaches point B, which represent the saturated pressure corresponding to ambient temperature. As vapour methanol condenses, generator pressure remains constant until it reaches point C, which represents the end of condensation process. From point C, ambient air is used to cool the generator, thus, generator pressure falls rapidly until it reaches point D, which represents the initial pressure of the unit. Evaporation of liquid methanol starts from D, and follows constant pressure line, due to evaporation process, heat is absorbed from evaporator enclosure, and the cycle ends at point A.

Figure (15) shows the axial surface temperature distribution with time. When the input power is 74W, ambient temperature is 26^{o}C, and active carbon-acetone pair is used. It can be seen from the figure that, at time zero the surface temperature of the pipe are at initial condition, as heating process starts, surface temperatures are increased with heating time. The maximum surface temperature of the generator zone is always at the middle, due to the heat lost from both ends of generator. Also it can be seen from the figure that there is a little increase in the evaporator section temperature due to condensation process in this part. The maximum temperature reached in the condenser section is equal to the saturation temperature corresponding to saturation pressure. The range of generator surface temperature are in the range of (40-105) ^{o}C, while it was about 36-38 ^{o}C in the condenser section, with heating time of 35min.

CONCLUSIONS

- Adsorption heat pipe can work at a relatively low temperature namely 70-100 ^{o}C, which can utilize waste heat from I.C. engines or other waste heat sources or even solar energy.
- Time required to achieve the cooling process was approximately 18-24 minutes.
- Using activated carbon – Acetone pair gave good behavior for the heat pipe due to the short cycle – time compared with that for activated carbon – Methanol

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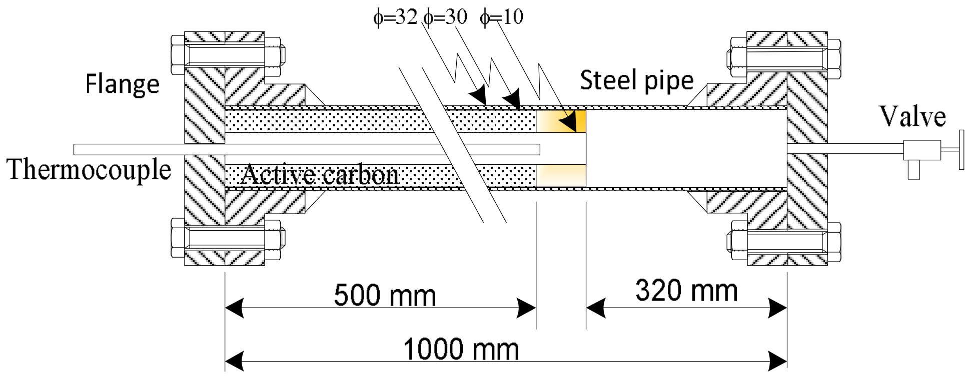
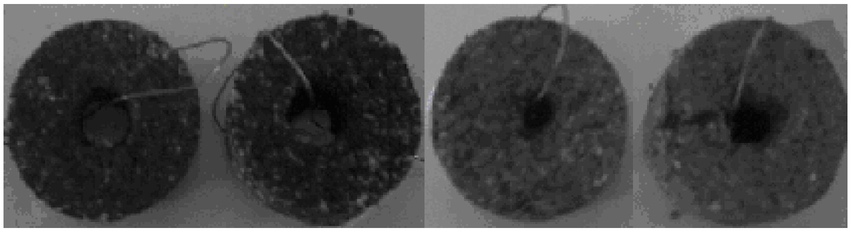


Figure (1) section in adsorption heat pipe.

Figure (2) flanges used to close tube ends.



a- 1:1 *b- 2:1* *c- 4:1* *d- 5:1*

Figure (3) A consolidated composite adsorbent.

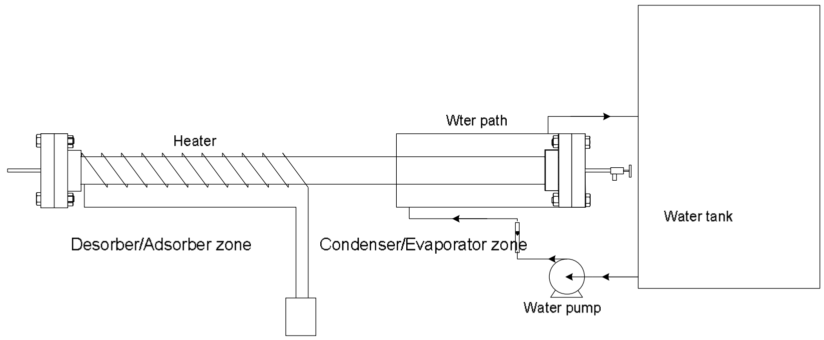


Figure (4) unit setup.

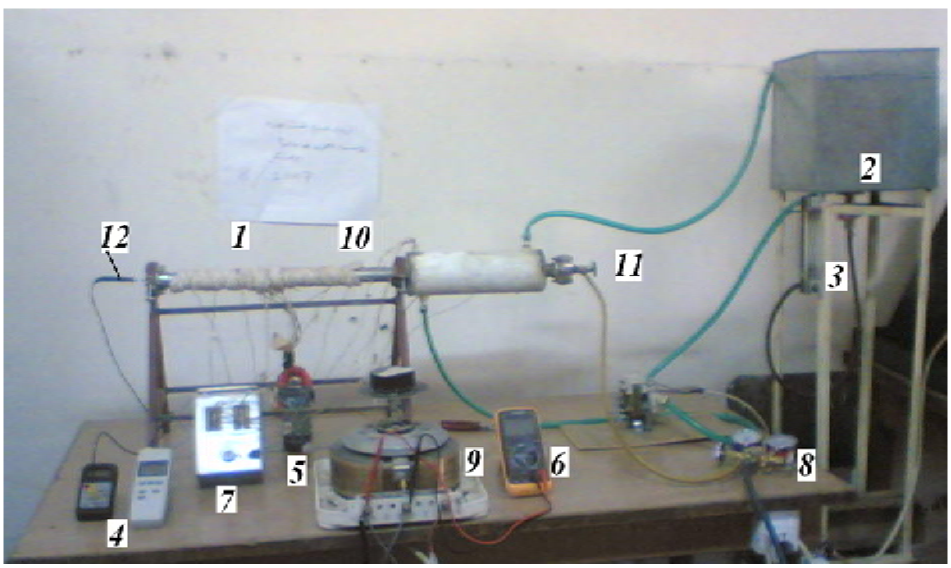


Figure (5) Photograph of the system rig.

1- adsorption heat pipe	**4-Digital thermometer**	**7- Selector switch**	**10- Electrical heater**
2- Water tank	**5- Ammeter**	**8- Pressure gauge**	**11- Service valve**
3- Flow meter	**6- Voltmeter**	**9- Variac**	**12Temperature probe.**

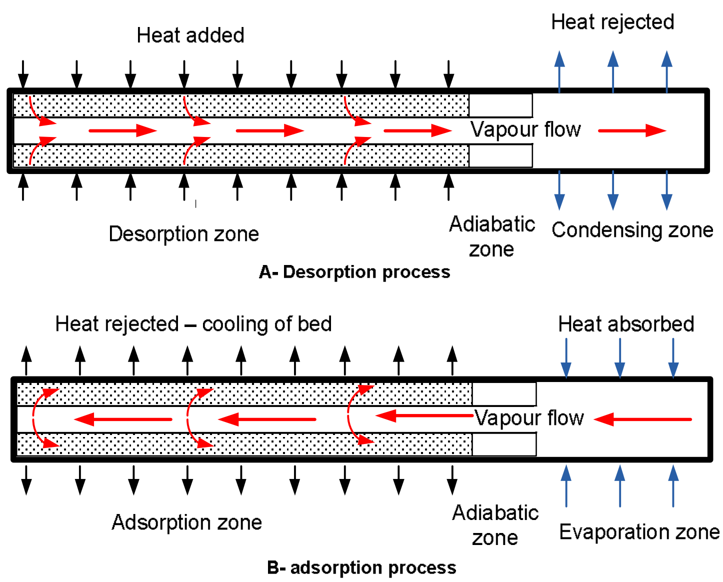


Figure (6) operation sequence of the adsorption heat pipe.

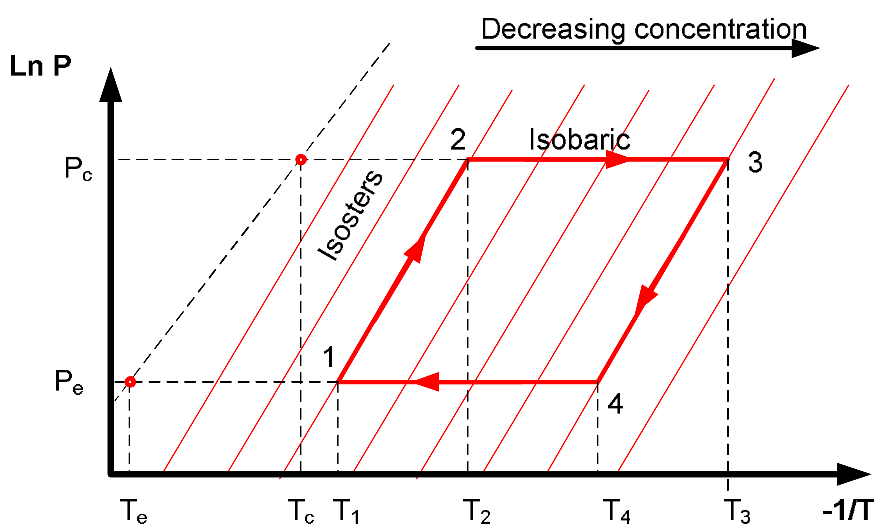


Figure (7) (P-T-x) diagram of the ideal basic adsorption cycle.

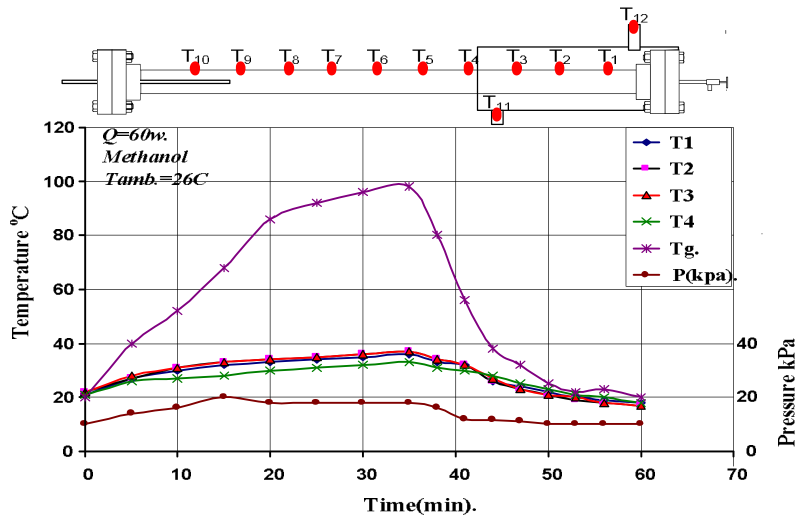


Figure (8) Variation of wall surface temperature and unit pressure, with time when the heat input is 60 W, adsorption pair is active carbon-methanol.

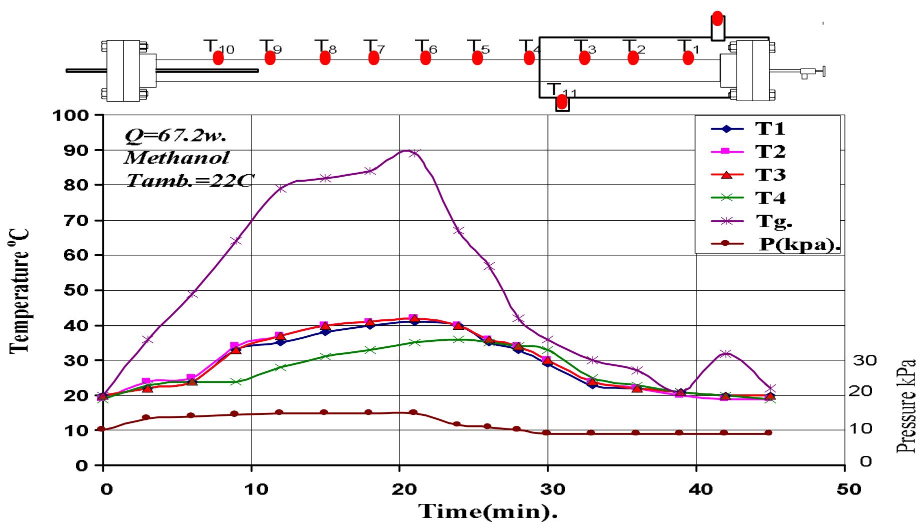


Figure (9) Variation of wall surface temperature and unit pressure, with time when the heat input is 67.2 W, adsorption pair is active carbon-methanol.

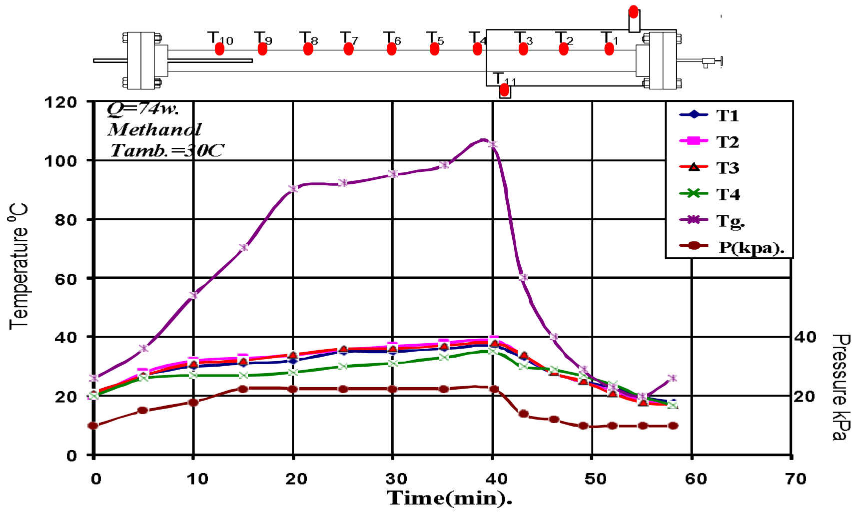


Figure (10) Variation of wall surface temperature and unit pressure, with time When the heat input is 74 W, adsorption pair is active carbon-methanol.

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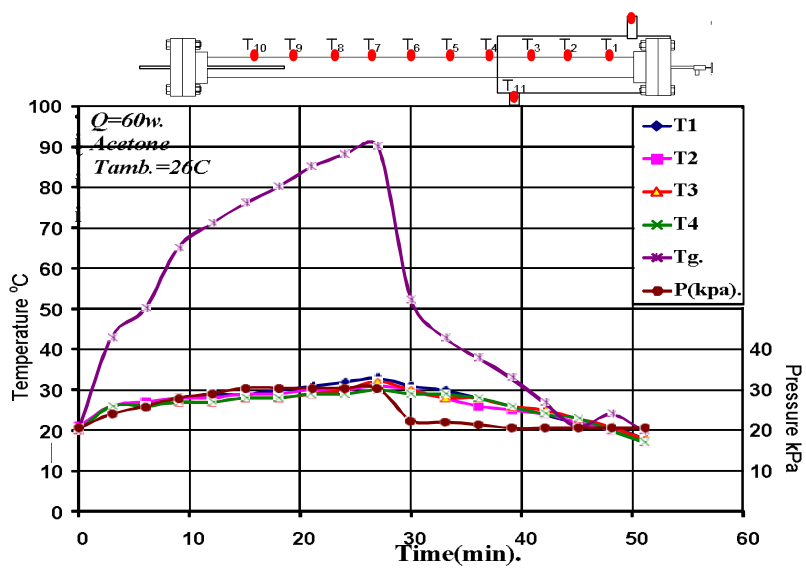

Figure (11) Variation of wall surface temperature and unit pressure, with time when the heat input is 60 W, adsorption pair is active carbon-acetone.

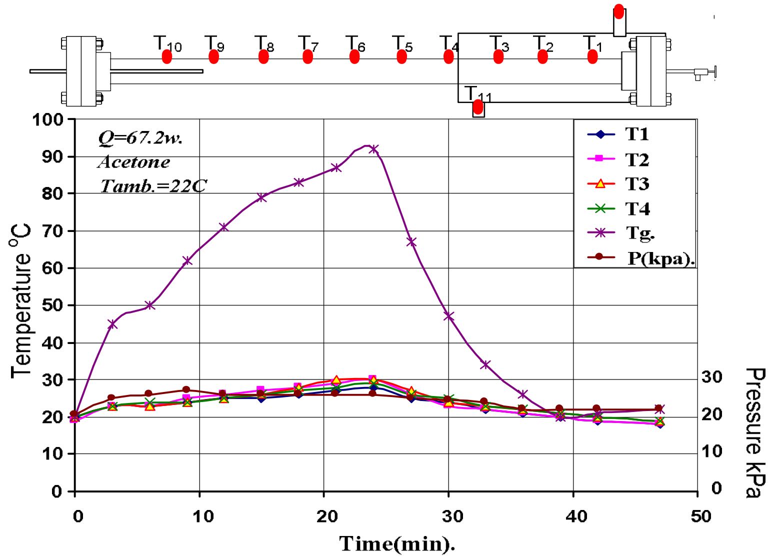

Figure (12) Variation of wall surface temperature and unit pressure, with time When the heat input is 67.2 W, adsorption pair is active carbon-acetone.

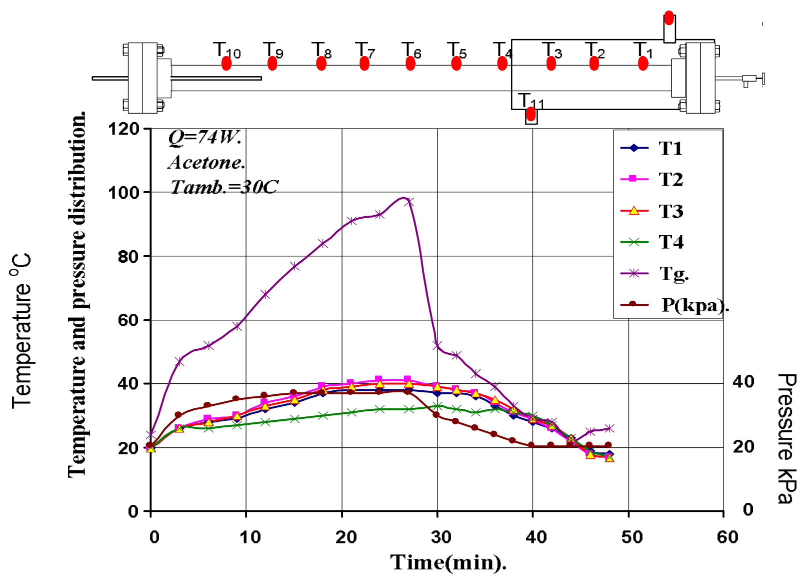

Figure (13) Variation of wall surface temperature and unit pressure, with time when the heat input is 74 W, adsorption pair is active carbon-acetone.

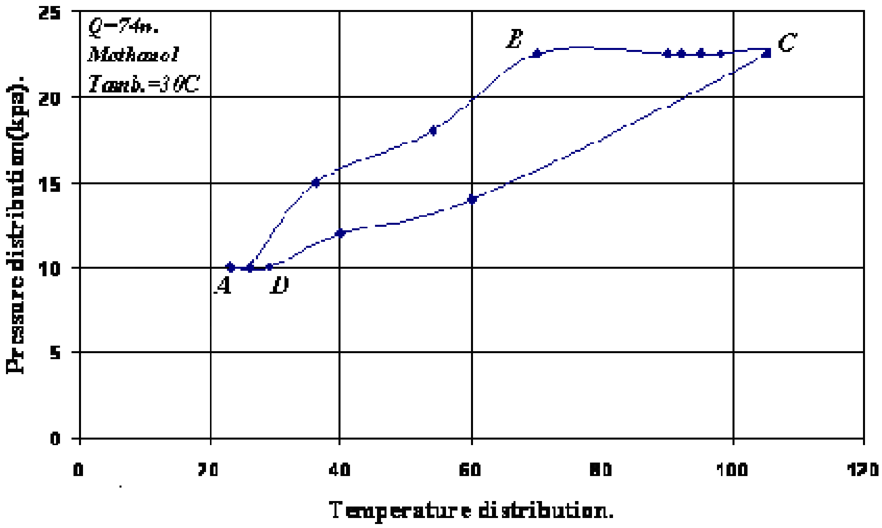

Figure (14) Adsorption cycle of the heat pipe, heat input is 74 W, active carbon-methanol pair was used.

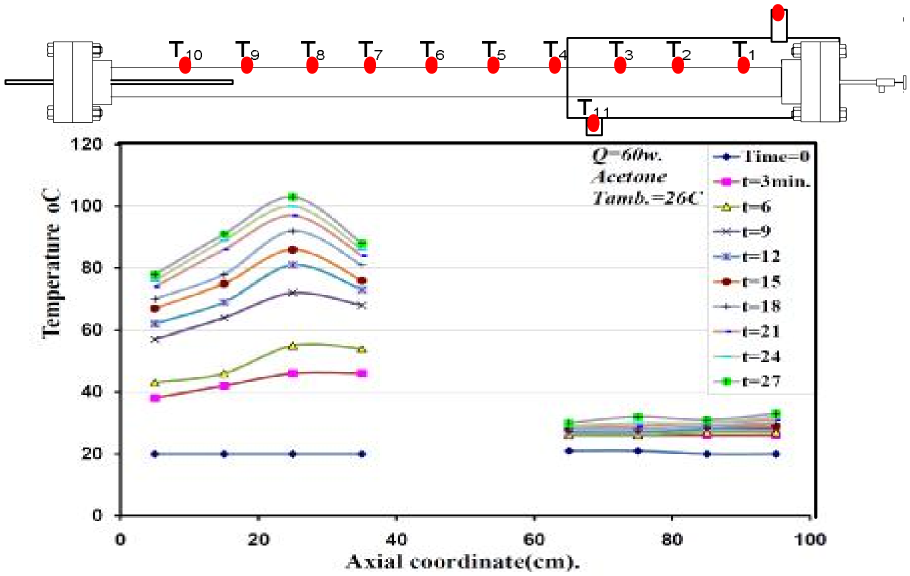

Figure (15) Variation of adsorption heat pipe wall temperatures with the axial direction and time.