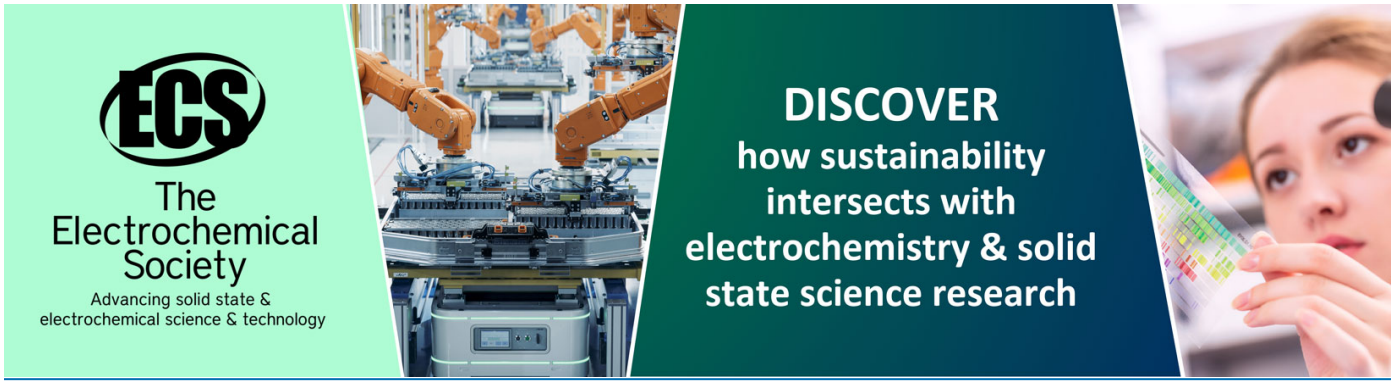
Functional design of heat exchange for pneumatic vehicles



Functional design of heat exchange for pneumatic vehicles

Z G Xu[1], D Y Yang[2] , W D Shen[2] and T T Liu[1]

[1] Shenzhen Research Institute of Shandong University, 518057, High-tech Zone A301, Virtual University Part, Shenzhen, China.
[2] School of Mechanical Eng, Shandong University, 250061, No 17923, Jingshilu, Lixiaqu, Jinan, Shandong, China.

zhgxu@sdu.edu.cn

Abstract. With the increasingly serious environmental problems, especially the impact of fog and haze, the development of air powered vehicles has become an important research direction of new energy vehicles. Quadrature test was done with different materials, i.e. stainless steel and aluminum alloy, at different inlet pressures, using different expansion gases, i.e. air, CO_2, for heat exchanging properties for pneumatic vehicles. The mathematics as well as simulation methods are used to analyze the different heat exchanging effects in the multistage cylinder. The research results showed that the stainless steel has better effects in heat exchanging than Aluminum Alloy; the intake pressure has little effect on CO_2 than the air in heat exchanging effect. CO_2 is better in heat exchanging than air.

1. Introduction

With the increasingly serious environmental problems, the transformation and upgrading of China's auto industry is becoming more and more urgent. In recent years, due to the deterioration of the natural environment, especially the impact of fog and haze, new energy vehicles are becoming more and more concerned.

French engineer Guy Negre [1] led the research team to develop a compressed air powered vehicle, more than 20 patents have been obtained in this field. There is no essential difference between the use of compressed air or compressed nitrogen for engines.

Researchers in University of Washington developed a liquid nitrogen powered vehicle prototype [2]. Their energy source is liquid nitrogen. Liquid nitrogen is heated to expand into the engine cylinder to drive the vehicle. There is no essential difference between the use of compressed air or compressed nitrogen for engines. Researchers in University of North Texas did the study of liquid nitrogen powered vehicles. A team lead by Dr. Carfos Ordonez, uses liquid nitrogen as power source, to drive vane type pneumatic motors [3].

Tsu-Chin Tsa from the University of California, Los Angeles, lead a R & D team, funded by Ford Motor Company, developed a hybrid power engine with no cam shaft [4]. High-pressure air is to start the car, when it is moving, normal gasoline combustion is to drive the car. When the car brakes slow

down or downhill, pneumatic engine can also be used as air compressor energy recovery, the new compressed air can be used as the starting power for the next start use.

A Korean ENERGINE company studied a compressed air and electric hybrid vehicles, called PHEV research. The weight of the major part is 30 kg, cylinder working volume is 0.8L, gas tank volume is 100L, the intake pressure of the engine is 1MPa, gas pressure is 30 mPa [5].

In China, researchers in Zhejiang University studied the working principle of a pneumatic engine, the characteristics of energy release of high pressure air under different conditions are analyzed, a number of experiments have been carried out on the pneumatic engine, it provides the theoretical basis and experimental data for the design and manufacture of pneumatic engines [6].

2. Heat exchanging for air powered vehicles

Heat exchanger, as in figure 1, is a key component for air powered vehicles, the heat transferring efficiency determines the performance of an air powered vehicle. However there exist contradictions, the typical one is that, if the heat transferring efficiency is to increased, the heat exchanger will be very large. Heat exchange efficiency determines the performance of the air powered vehicle. The heat transferring efficiency is to be increased, but the volume is constrained to a certain space, it is a contradiction.

This contradiction is problem, and this problem is to solved by TRIZ contradiction matrix. Two contradiction parameters should be firstly recognized, according to the problems existing in the heat exchanger, the no.39 parameter, i.e. productivity, and the no.8 parameter, i.e. the static volume is identified. The solution principles in the conflict matrix can be found as the follows: no 2 principle, i.e. separation; no 35 principle, i.e. parameter changing; no 37 principle, i.e. thermal expansion.

The no.2 principle, i.e. separation is accepted. The "instance effect increased with the increase of temperature of heat exchanging can be used as an example, so the single cylinder is changed to a multi-stage cylinder, a two-cylinder structure is utilized, and the analyzing of the heat exchanging, and the two stage expansion diagram is shown in figure 6.

The high pressure gas in the first level cylinder, exchanges heat with low pressure gas discharged through a heat exchanger, and the first cylinder absorbs heat from the external environment, and then enters the second stage cylinder, this process can improve the thermodynamic properties, which was close to the isothermal process, and the aerodynamic efficiency of the engine is further improved.

The heat exchanging efficiency has a great influence on the performance of the engine, and the heat exchanger is a device for realizing the heat exchange between two or more than two fluids with different temperatures [6].

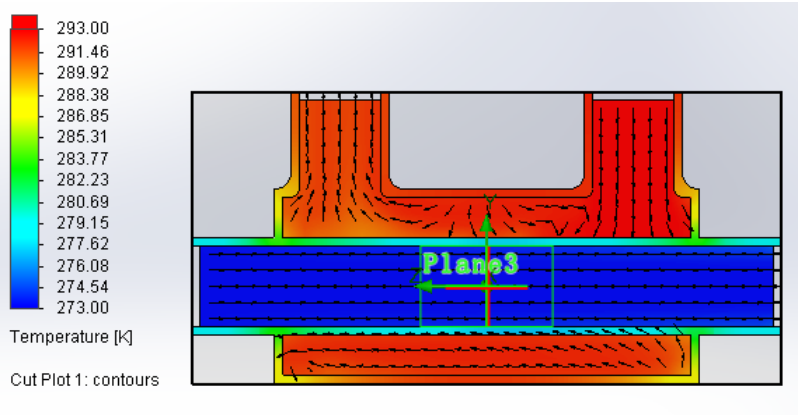


Figure 1. Heat transfer effect of casing heat exchanger.

According to its working principle, the heat exchanger can be divided into three types: the wall-type, the mixed type and the regenerative type. This paper chooses the wall-type heat exchanger.

In this paper, the casing heat exchanger is analyzed firstly, and the heat exchanger is made of several concentric tubes with different diameters. In this kind of heat exchanger, some fluid go through the inner tube, other fluid go through the gap between tubes, both can use a higher flow rate, so the heat transferring coefficient is relatively high. In addition, in this heat exchanger, two kinds of fluid can go oppositely, and the heat exchanging effect is getting higher.This heat exchanger has the advantages of simple structure, convenient operation, high pressure etc.

The low temperature gas enters from the gas entrance, and departs from the air outlet, the heated water comes into the liquid from the entrance, and exits from the outflow of liquid. The air velocity is 10m/s, the temperature is 273K, the liquid flow is 0.02kg/s, the temperature is 293K, and the heat exchanger material is stainless steel, the analyzing results are as follows.

It can be seen from the figure that the temperature of the gas outlet is very low, and the heat transfer efficiency of the heat exchanger is not high enough, which is not suitable for the heat exchange of the air powered vehicle. So it is necessary to improve the efficiency of the heat exchanger. Considering the "heat radiation" effect, i.e, solar energy is introduced to heat the gas, and the above method of heating the liquid gas is more convenient and better, so the design of a solar heat exchanger is as in figure.5. The low pressure low temperature gas discharged from the first stage cylinder, enters the heat exchanger, and the heat exchanging is done in the two stage cylinder to continue to expand and do works.

3. Orthogonal experiment of heat exchanger

The solar heat absorbing plate is equivalent to a constant power source, its power is influenced by many conditions, this paper set up the power of 50W, the gas entrance temperature is 273K, temperature 293K, under different conditions, the effect of heat transferring is different, corresponding to a number of different exchanging plan, for each program number with different numbers for different schemes, its meaning is shown in figure. Its specific meaning is shown in the following table:

Table 1. Different program details.

No	Material	Inlet pressure	Expansion gas
H141	Stainless steel	4atm	air
H142	Stainless steel	4atm	CO_2
H151	Stainless steel	5atm	air
H152	Stainless steel	5atm	CO_2
H241	Aluminum alloy	4atm	air
H242	Aluminum alloy	4atm	CO_2
H251	Aluminum alloy	5atm	air
H252	Aluminum alloy	5atm	CO_2

In order to compare the heat transferring effects of the influence of different materials, different inlet pressures and different gas. Eight schemes should be compared, in order to reduce the number of experiments, this paper used orthogonal test to select a representative research program.

The orthogonal test is very suitable for multi-factor analysis, through the orthogonal experiment to analyze the effect of each factor on the test results, the relationship can also be distinguished among the various factors and their interaction between primary and secondary factors etc, and the best combination is finally selected. More information could be obtained with less number of tests by orthogonal test [7]. The variable factor is the material, inlet pressure, expansion gas, each factor is set to two levels, this paper uses the three factor two level experiment, as shown in the following table2.

Table 2. Factors and different levels.

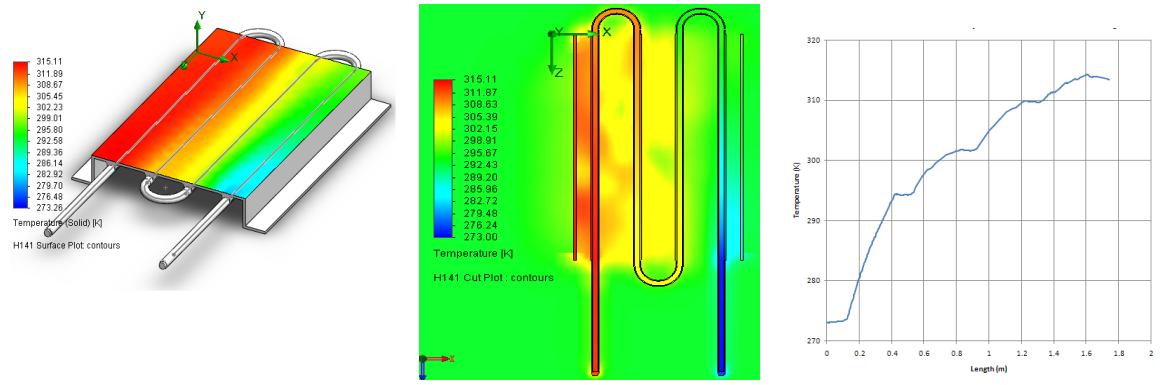
level	Factor A, material	Factor B, inlet pressure	Factor C, expansion air
1	Stainless steel	4atm	air
2	Aluminum alloy	5atm	CO_2

Take L4（2^3）as the orthogonal results as in table 3.

Table 3. Orthogonal test table.

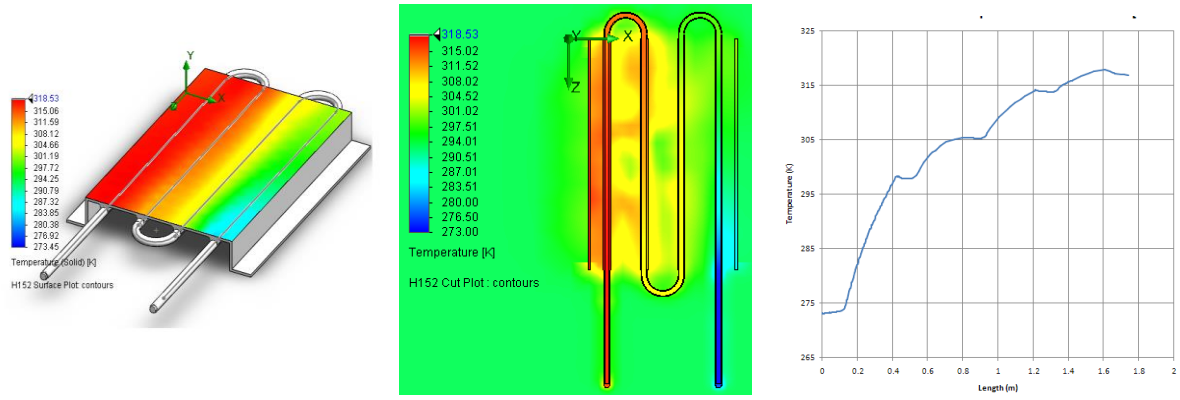
no	A	B	C
1	1（Stainless steel）	1（4atm）	1（air）
2	1（Stainless steel）	2（5atm）	2（CO2）
3	2（Aluminum alloys）	1（4atm）	2（CO2）
4	2（Aluminum alloys）	2（5atm）	1（air）

Table 3 shows that the program are chosen as H141, H152, H242, H251, and the simulation results are as follows:



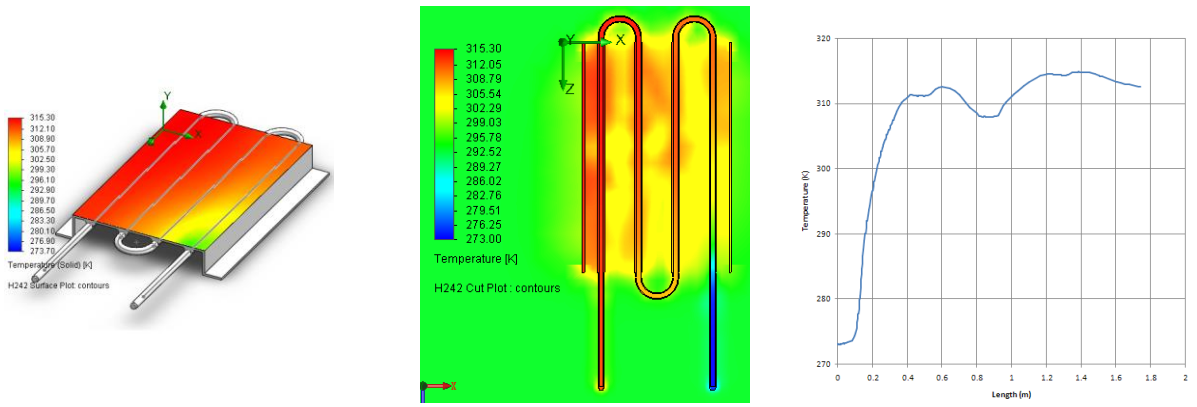
(a) Surface temperature. (b) Temperature of air duct section (c) Temperature change

Figure 2. Temperature change of H141 scheme.



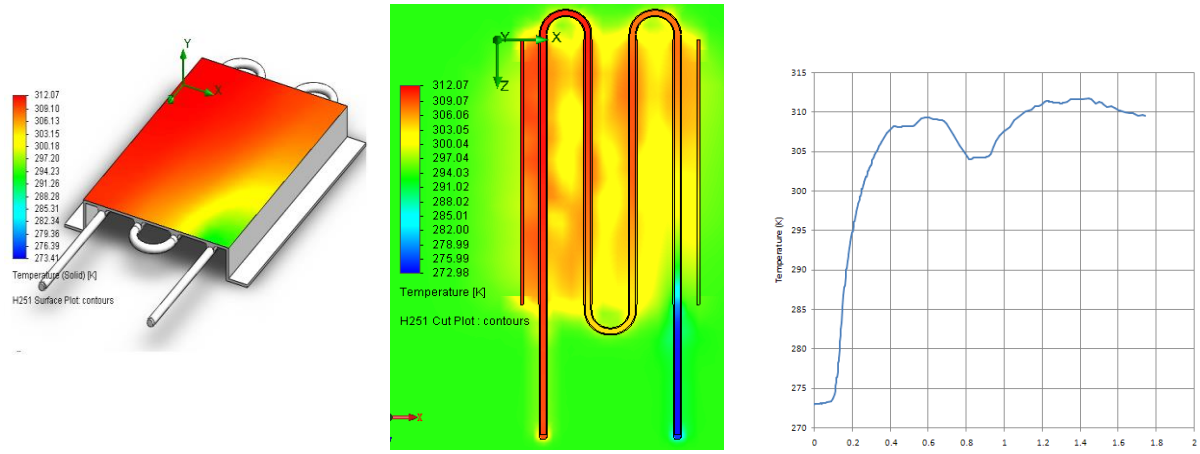
(a) Surface temperature. (b) Temperature of air duct section (c) Temperature change

Figure 3. Temperature change of H152 scheme.



(a) Surface temperature. (b) Temperature of air duct section (c) Temperature change

Figure 4. Temperature change of H242 scheme.



(a) Surface temperature. (b) Temperature of air duct section (c) Temperature change

Figure 5. Temperature change of H251 scheme.

Table 4 orthogonal test results

No	plan	A	B	C	Outlet temperature
1	H141	1	1	1	315.11
2	H152	1	2	2	318.53
3	H242	2	1	2	315.3
4	H251	2	2	1	312.07

From table4, the optimal solution is set as $A_1B_2C_2$, namely H152 scheme, the simulation results showed that the stainless steel material is better than Aluminum Alloy in heat exchanging effect. And the intake pressure has little effect on heat exchanging. CO_2 is better than air in heat exchanging. When the inlet temperature is 273K, through the absorption of solar energy, the outlet temperature is about 318K. And the thermodynamic process of the cylinder is approximately equal to a isothermal expansion process, thereby the output power of the pneumatic engine is increased.

4. Thermodynamic analysis of multistage expansion

The thermodynamic process of the multistage expansion is different from that of the single stage expansion. Take the two stage expansion as an example, the thermodynamic process consists of the following three stages, the first is the polymorphic process, experience and process, and finally the polymorphic process is shown in the end of the expansion.

Thick line in Figure 6 is the thermodynamic process of two stage expansion, 1-3-5 curve stands for the isothermal process, 1-2-5 curve stands for the 'polymorphic process.

Assuming that the environmental temperature is set in 293K, the detailed process is as follows, 1-2 curve is a polymorphic process, and the gas pressure decreased, the volume expanded and temperature reduced. Curve 2-3-4 is an isochoric process, gas absorbs heat from the outside environment, the temperature and the pressure rises with the constant volume; curve 4-5 is a two stage expansion polymorphic process.

The ordinary polymorphic multistage expansion processes consider the heat transferring with the environment, the temperature can not exceed the ambient temperature, when the solar energy is absorbed, the temperature will be higher than the ambient temperature, it can reach 318K, where more energy are released.As is shown in the figure 8, the energy released is the area of 3-4-5-3, and the energy of the two stage expansion is more than that of the single stage expansion, which is the area of 2-3-4-5-5 '-2.

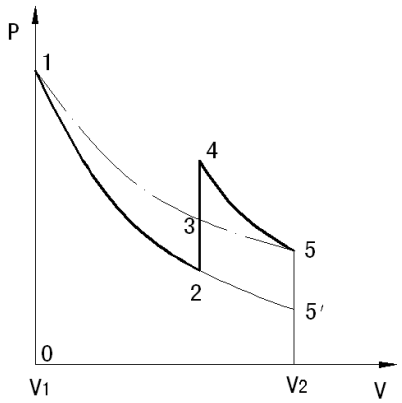


Figure 6. Two stage heat expansion thermodynamic processes.

5. Conclusions

The research results showed that the stainless steel has better effects in heat exchanging than Aluminum Alloy; the intake pressure has little effect on CO_2 than the air in heat exchanging effect. When the inlet temperature is 273K, through the absorption of solar energy, the outlet temperature is about 318K, make the thermodynamic process of cylinder approximately equal to an isothermal expansion process, thereby the output power of the pneumatic engine is increased.

6. Acknowledgment

The above-mentioned research work is supported by the Science, Technology and Innovation Commission of Shenzhen Municipality, JCYJ20160510165328965 and the Chinese NSFC, 61272017, P.R. China.

References

[1] Cheng Sen, Li Sanchao. Carbon fiber gas car tank. automotive and safety,2001,(9):44-45.

[2] He Cunxing, Zhang Tiehua. Hydraulic transmission and pneumatic drive, Huazhong University of Science and Technology press, Wuhan, China, 2000.

[3] Prabhakar G, Goel A.A functional modeling for adaptive design of devices in new environments, Artificial Intelligence in Engineering Journal(Special Issue), 1998,12(4):417-444.

[4] G. Altshuller. Creativity as an Exact Science. Gordon and Breach Science Publishers,1984.

[5] Tai, Chun, Tsao, Tsu-Chin, M. B. Levin, G. Barta,and M.M.Schechter,"Using Camless Valvetrain for Air Hybrid Optimization,"SAE Paper 2003-01-0038 presented in SAE World Congress, March 2003, Detroit, MI. Also in SAE World Congress 2003 Special Publications (SP-1752), ISBN: 0-7680-1175-2.

[6] Robert F V. Fuel of the future? In: Electric and Hybrid Vehicles Technology'98, 1998: 124-127

[7] Williams J, Knowlen C, Mattick A T, et al. Quqsi isothermal expansion engines for liquid nitrogen automotive propulsion. SAE 972649, 1997