PRODUCTION AND EXPLOITATION OF THERMOELECTRIC AIR CONDITIONING SYSTEMS FOR VEHICLES

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In the paper more than 10-year experience of thermoelectric devices batch manufacturing is described for the field of their obvious advantages. This field of application includes thermoelectric air conditioning systems which have shown their competitive advantage when used in vehicles of elevated vibration where compressor equipment application is difficult because of leakage of refrigerant. Energy characteristics of air conditioners for tractors, excavators, tanks, locomotive driver's cabins and cranes are described. Thermoelectric (TE) air conditioners mechanical test data as well as operation experience in vehicles are presented. It is shown that consumption of tellurium, which is a strategic component for thermoelectric materials manufacturing, may be lowered to 40 grams per 1 kW of cooling.

Generally, mass application of thermoelectrics in automotive industry is limited by two reasons, namely relatively low efficiency of energy conversion and limited raw material resources for production of thermoelectric materials (TE). Nevertheless there is a field of application for thermoelectric cooling devices in vehicles where such products have obvious advantages as against compressor systems. This is the field of application for vehicles of elevated vibration conditions where thermoelectric air conditioners application is quite reasonable.

The fact is that thermoelectric cooling devices on the base of compressor systems are unworkable because of compressor systems refilling has no economic sense due to refrigerant leaks and is sometimes impossible.

Such vehicles of high mechanical load include tractors, excavators, cranes, tanks, and other military machines.

Health hazard resulting from refrigerant leaks also sometimes makes impossible compressor systems applications. Such cases may include locomotive driver's cabins air conditioning where driver asphyxia may cause a traffic accident.

TE air conditioners development and studies have started as early as 1960-s. The articles of French scientist J. G. Stockholm [1] should be mentioned as the most systematic.

In this article the 15- year manufacturing and operating experience of TE air conditioners for automotive industry is presented, namely for those fields of application where the application of compressor systems is impossible.

The most important criterion for some power unit application on a vehicle is the effectiveness, which is expressed as ratio of cooling capacity (Q_0) to power consumption (P) for cooling systems. It is the so called Coefficient of Performance (COP).

$$COP = \varepsilon = Qo / P \quad (1)$$

For compressor systems COP is usually ε~2. For thermoelectric module or the so called Peltier element, COP does not depend on cooling capacity, as against compressors, but depends on temperature difference ΔT. Fig.1 shows that COP achieves the value of 1.0-1.7 when temperature difference is 20-30 ^{0}C and the hot temperature is about +50^{0}C (this is a typical operation mode for air conditioning systems).

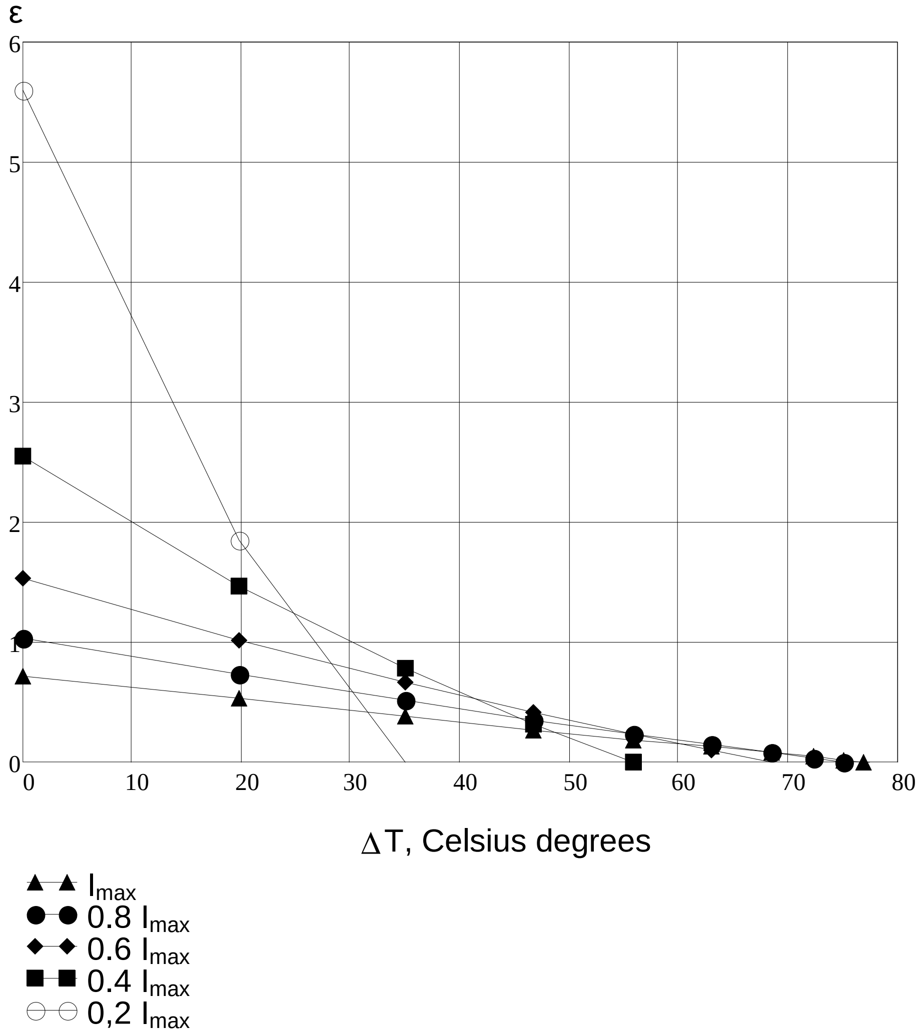


Fig.1: ΔTdependence of COP

The interesting feature of TE air conditioner is its transforming into heater when feeding DC is reversing the polarity. Proceeding from energy, the most important matter is that the module starts to act as heat pump device, which produces the heat greater then power consumption. Actually, if for resistance heater the generated heat amount is exactly equal to electric energy input, then in TE module heat amount on hot side of module is equal to energy consumption P plus amount of cooling Q_0 given off.

$$Qh = Qo + P \qquad (2)$$

Ratio of produced heat to energy consumption is called Heating Coefficient-μ.
From equations (1) и (2) we can see that ε and μ are related simply as:

$$\mu = 1 + \varepsilon \qquad (3)$$

and for operational important applications μ=2.0-2.5.

Consequently TE air conditioners insufficient effectiveness in the mode of cooling may be compensated with the acting in the mode of heating.
Developed and manufactured in our Companies TE air conditioners have successfully passed all tests including military standard tests. The most important experience in TE air conditioners developing and operating has been gained when they had been supplied for Russian serial tanks T-90C (CK). Table 1 and Fig.2-Fig.4 show Technical Data for this type of air conditioning system.

Table 1
Technical data on TE air conditioner TEK-03

Cooling capacity at ambient temperature of +50^{0}C and relative humidity of 45%	3500 Kcal/hr
DC supply voltage	27,5±1 V
Energy consumption	3.2 kW
Total cooling air flow rate	210-750 m^3/h
Cooling agent	Ethylene glycol aqueous solution
Cooling system volume	10 L
Run time	24 h
Total weight	50 kg
Range of temperatures	From -40^{0}C to +70^{0}C
Air velocity over operators	0,5 m/s
Relative humidity of cooled air	30-75%
Cooling Unit Outlet Air Temperature	Not less then 25^{0}C lower than Cooling Unit Inlet Air Temperature
Warranty period	10 years
Lifetime	15 years

Fig. 2. Tank T-90C (CK)

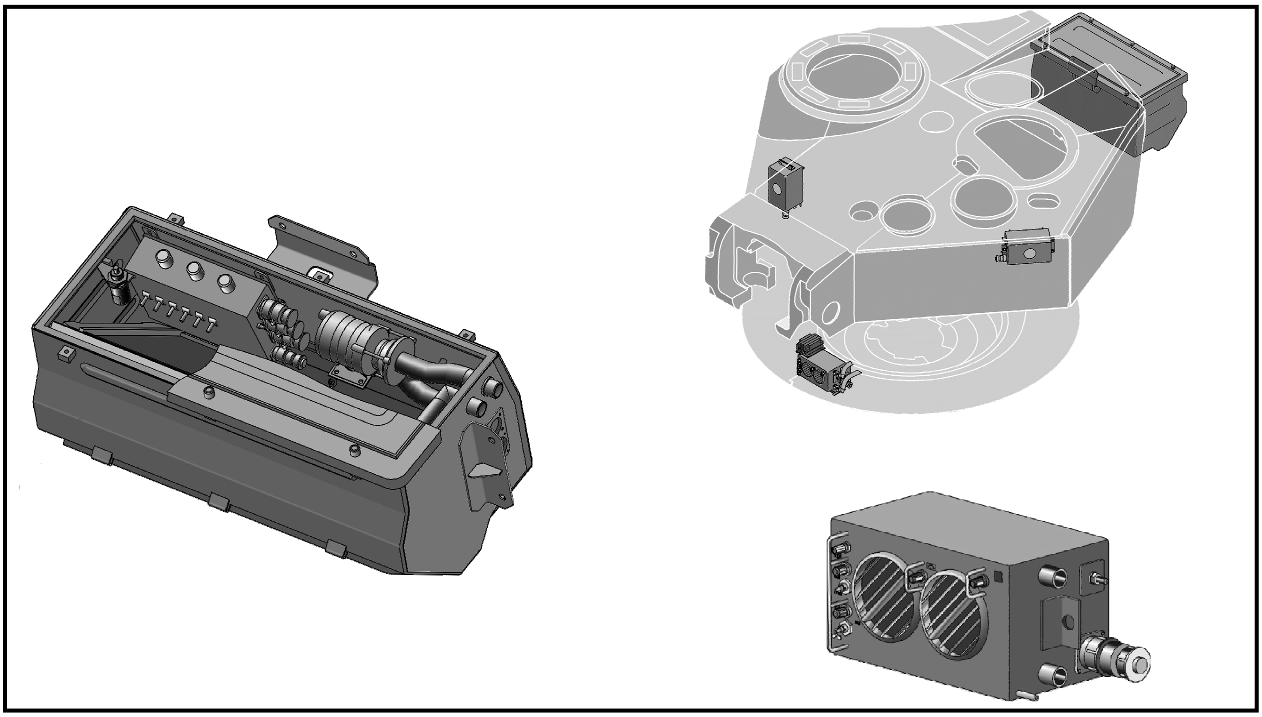


Fig. 3. Thermoelectric air conditioner TEK-03 for tank T-90C (CK)

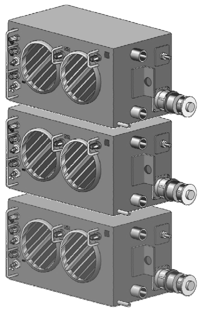
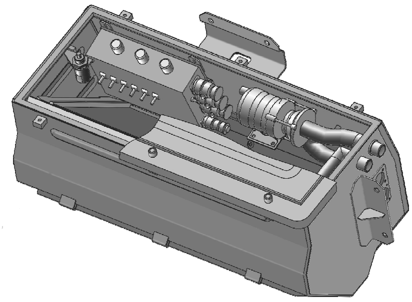
	3 Cooling Units (140x140x240) hose couplings electric cables	Located inside tank turret
	Radiator for heat disposal with two blowers Electrical fluid pump Control unit	Located outside on Tank Turret in mounting box (850x500x400)
	Inlet and outlet pipes for cooling agent	Located Outside the Turret

Fig. 4. TE air conditioner TEK-03 Set

These products have been delivered for the last 7 years and showed good results not only for Russian climate but for hard desert conditions in countries where exported.
The advantages of above described TE air conditioner are:
- resistance to vibration and impact stress (single or repeated mechanical shocks of 500/20g; sinusoidal vibration with the range of 5-500 Hz and with vibration acceleration range of 3g);
- stability when careen and sway occur;
- high reliability;
- ease of maintenance & operation;
- TE air conditioner workability at high ambient temperatures above $+50^0$C;
- fire safety and environmental friendliness;
- independent switch-on and switch-off of every cooling unit;
- bacterial protection for cooling plates

Table 2 shows TE Air Conditioner Technical Data for vehicles having cabin space not more then 1.8 m^3.
These are the series of Russian tractors and excavators.

Table 2

Technical data on climate control system for tractors and excavators

Cooling capacity	1500 Kcal/hr
Heating capacity	2000 Kcal/hr
Electrical power	2000 W
Air flow	200 m^3/hr

Table 3 shows Technical Data for TE air conditioners for electric locomotive cabin cooling.

Table 3

Technical data on TE air conditioner for electric locomotive cabin

Cooling capacity	4000 Kcal/hr
Air flow	600 m^3/hr
Outside temperature	up to 50^0C
Feeding voltage	24-28 V
Electrical power	4500 W
Mass of conditioner without cooling liquid	25 kg

Table 4 shows Technical Data for TE air conditioners for cranes.

Table 4

Technical data on TE air conditioner for cranes

Cooling capacity	3500 Kcal/hr
Air flow	565 m^3/hr
Outside temperature	up to 50^0C
Feeding voltage	380 V
Electrical power	4000 W
Mass of conditioner without cooling liquid and voltage converter	40 kg

The above described applications of air conditioning systems in specific vehicles have a feature that their mass production is possible due to solving the key problem for low temperature thermoelectricity, namely raw material resources limitation for production of bismuth telluride. As is known, tellurium does not occur in nature as pure mineral and is produced as by-product in copper production. Namely, tellurium production level directly depends on the level of world copper mining and is equal to 400-600 tonnes per year in terms of pure tellurium.

In recent years “classic” consumers of tellurium, such as metallurgy and thermoelectricity, have faced a rapidly growing “competitor” i.e. photovoltaic solar panels production. The photovoltaic solar panels are manufactured on the base of CdTe films, so this has resulted in boom in prices for tellurium from $50 to $200-250 per kg during last 5 years.

Of course, there is a hope that ROHS Directive prohibiting cadmium application will limit the solar energy development on the base of CdTe, but in any case current tellurium production level is extremely low. What are the real possibilities for thermoelectricity in terms of production levels of devices on the base of tellurium?

The mass of thermoelectric material for manufacturing of TE module with fixed cooling capacity is inversely proportional to square of dice height in thermoelectric module.

Unfortunately this way for lowering consumption of TE material has limitations including:

- decrease of module operating efficiency because of contact resistances role increase with dice height lowering;
- risk of module destruction at cyclic operation (ON/OFF) because of mechanical stress increase in modules with low height dices;
- difficulty of work with thin slices of fragile TE material.

For a long time our Companies have been working on raw material consumption decrease connected with dice height lowering in modules. Due to adoption of bismuth telluride polycrystalline material produced by extrusion technology and application of so called glued module, which had been patented in a number of countries, the Companies have succeeded to achieve mass production of modules of 0.85 mm height of dices. This helps to achieve tellurium consumption to 100 – 125 g per conventional air conditioner with cooling capacity of 1 kW. In the near future adoption of shorter dices of 0.6 mm and even 0.4 mm will help to make this tellurium consumption lower to 40 g per 1 kW of cooling.

Supposing that new mass thermoelectricity application in automotive industry may demand 100 tonnes of tellurium per year, we can evaluate that this raw material amount is sufficient to produce 2.5 million units per year with cooling capacity of 1 kW each.

Of course, it’s clear that this amount is sufficient for only specific applications like those described above.

Literature

[1] J.G.Stockholm. “Current state of Peltier Cooling”, Proc. of 16-th. International Conference On Thermoelectrics, 26-29 Aug.1997, Dresden, Germany, pp.37-46.

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