The engine-recoverer of secondary energy thermal sources based on a Curie point effect for magnetic materials

V V Papin, R V Bezuglov*, E M Dyakonov and D A Shaforost
Platov South-Russian State Polytechnic University (NPI), 346428, Novocherkassk, Russia

*bezuglov@npi-tu.ru

Abstract. The article discusses one of the most important issues of the fuel and energy complex - the energy efficiency and the most complete use of the flue gases heat. A review of existing technologies for the heat utilization, including some designs of magneto-thermal engines, is carried out, their structural and technical characteristics are considered. A technology is proposed that ensures not only the utilization of exhaust gases from power plants, but also the application in the field of waste management, for example, increasing the energy efficiency of waste incineration technologies. The idea is to use the Curie point effect when designing a recovery engine that utilizes the waste heat of secondary energy sources. The applied potential of using the effect is based on the possibility of utilizing the heat of various secondary energy sources, such as exhaust gases of heat engines, up to low potential sources, since today there are materials that carry out a second-order phase transition already at 20 °C.

1. Introduction
As is known, the temperature at which a metal loses its ferromagnetic properties is called Curie temperature or Curie point. This phenomenon is also known as phase transition of the second kind. This effect can be used to convert thermal energy into mechanical energy and then to electrical energy. Despite the technology is very promising technical check is extremely small. Now primitive laboratory samples have absolutely no practical efficiency.

Within the framework of this study we offer several own structures of the unit (thermomagnetic engine). This engine utilizes a waste heat of power facilities such as gas turbine and gas piston plants, waste exhausts in the industry and communal sector, up to discharge air from the ventilation system.

2. Heat Recovery Technologies
There are many scientific works devoted to the problem of heat disposal at the moment. Most of these works, however, has some underreporting in terms of the coverage of existing technologies and, most importantly, in terms of addressing all their shortcomings.

In particular, the work [1] considers various methods the heat recovery of exhaust gases from power plants in order to increase their efficiency, save organic fuel and increase energy capacity. The main reference is made to the use of a steam-gas installations and gas turbine, which have not yet spread properly in Russia. Issues of these power plants operation are not considered, which doesn’t allow to see their shortcomings.

Simulation of heat recovery systems based on theoretical dependencies is considered and an
example of simulation based on empirical patterns obtained experimentally is given [2]. Issues of heat recovery in municipal heat supply systems are considerate in articles [3, 4]. In particular, a scheme of utilisation and heat conversion of outgoing flue gases of district gasified boiler house is considered. This method using a ORC plant requires quite a large capital cost.

Three technological directions of flue gases heat recovery without condensation of water vapour are specified [5]. Conclusion is made on possibility of flue gases heat recovery during coal combustion, methods of economic effect from utilization are proposed. The publication [6] provides an overview of the boiler exhaust heat recovery methods. The operation doesn’t take into account the hydraulic influence of the flue gas utilizer on the gas and water duct.

One method of improving the efficiency of gas turbines cycles is the use of recovery boilers. One of the most promising methods of increasing the efficiency of gas turbines is the injection of water vapor from the recovery boiler into the gas duct [7]. However, the introduction of technology requires a revision of the plant's technological scheme.

In addition to research on gas turbine plants, research is under way in the field of turbine technologies. Studies of turbines possible performance characteristics are carried out [8] and studies of perspective microenergy complexes based on steam turbines are carried out [9].

3. Technologies based on phase transition effect the second kind

As mentioned earlier, there are power plants based on the use of Curie point. An example of a device operating on the above principles is the device disclosed at the Russian patent № 2379820 «Method of converting thermal energy into electric energy». The invention essence is that the cyclic operation of the piston in closed chambers heats/cool the air during compression/ expansion. Heated/ cooled air goes through hoses heats/cool s low Curie point inserts. At the same time, this air interrupts the magnetic core creating an alternating magnetic field and causing EMF in the receiving windings. After windings current goes to rectifiers. Excitation winding is required for plant operation [10].

Another use of phase transition heat the second kind is «Device for conversion of thermal energy into electric energy» [11].

Patents «Method of converting thermal energy into electric energy and apparatus for realising this method» [12] and «Device for direct conversion of thermal energy into electric energy» [13] have a similar principle of operation. They use for their work the phase transition effect the second kind by interrupting the magnetic core.

4. Piston engine disposition options

Here’s how the engine works. Ferromagnetic properties are lost when the Curie point temperature is reached at the engine performing piston (Figure 1). Then magnet located near the piston stops acting on it and the piston is shifted towards prevailing force applied to it and work is performed. Piston is provided with holes through which gas passes. It was done for the best heat transfer of the exhaust gases used by the engine.

Figure 2 shows the position of the performing piston in a cold state, with ferromagnetic properties and in hot state, in case of their loss. In this example, the prevailing force is gravity. However, in 2 possible engine designs, other prevailing forces, such as elasticity, or static pressure, etc. need to be investigated.
Figure 1. The performing piston of an engine using waste heat.

Figure 2. Position of the engine piston relative to the magnet, before and after reaching the Curie point temperature.

The work performed by the engine piston can be directed to the crankshaft (Figure 3, 4) for further transmission to the rotor-type electric generator, or directly to the reciprocating generator.

Figure 3. Vertical layout of the performing piston.

Figure 4. Horizontal layout of the performing piston.

The following points should be studied as part of the engine design optimality study (in terms of energy and feasibility):

- principle of operation: rotary or piston;
- geometry of the operation piston;
- material of the operation piston;
- type of the magnet;
- geometry of the magnet;
- method of the operation piston flow;
- device providing action of prevailing force acting on piston for its performance;
- space layout of the performing piston: vertical (figure 2 and 3), horizontal (figure 4);
- amount of the performing cylinders;
- type of the gas distribution system;
- type of the electric generator.
5. Waste heat utilization schemes

Preliminary studies have created sketches and schematic diagrams of several variants the engine using waste heat. In the course of further research these diagrams will be improved, supplemented, calculated in detail. They will also be compared in terms of energy balances and techno-economic criteria with each other and other variants developed during the project implementation.

Figure 5 shows the diagram of the waste heat engine with vertical arrangement of cylinders and ring type magnets. Cylinders with longitudinal channels are used. There’s a rotor-type electro generator. Power transmission system from piston to electric generator is crankshaft. Valve timing system driven by crankshaft.

![Diagram of the engine](image)

**Figure 5.** Scheme of an engine using waste heat with longitudinal channels of the performing piston

Note that the heat transfer efficiency is greatly influenced by the thermal resistance of the surface. These resistances can vary significantly depending on the contamination of the heat exchange surface.

Here’s how the engine works. The performing piston 1 under action of magnetic field created by magnet 2 is in upper position (left cylinder). Valve distribution system 5 supplies hot flue gases (left piston) and cooling air (right piston). A hot gas enters the piston through longitudinal channels, heating it, and is removed to the atmosphere. Piston loses ferrimagnetic properties when it reaches Curie point temperature. The magnetic interaction force stops acting on the piston and it starts to move downwards under the action of the prevailing gravity force, rotating the crankshaft through the traction 3. At the same time the right piston (that has heated and lowered down before that), having cooled from the air passing through it and having restored magnetic properties, is directed upwards. The right piston rotates crankshaft in same direction.

Pistons change positions, crankshaft 3 turns, bringing generator into operation and through traction, switching system of valves 5. The valve system switches the gas flows and then cooling air goes through the left cylinder and flue gas goes through the right cylinder. The cycle is repeated. The air that cools the piston is heated. This air can be used in an engine that flue gas heat is recycled, providing additional heat recovery. This principle is disclosed at the following diagram (Figure 6).
Figure 6 shows a diagram of a waste heat engine with vertical cylinder layout and rectangular magnets. These magnets are not indicated in the diagram because they are in a plane perpendicular to the drawing. Cylinders with transverse channels are used. There’s a rotor-type electro generator. Power transmission system from piston to electric generator is crankshaft. Valve distribution system is not made as a separate circuit. Gas distribution takes place when the performing piston closes the channel with air/gas. Access to the other gas flow is blocked by the surface of the piston itself, this simplification being an advantage over the previous scheme.

Here’s how the engine works. Performing piston 1 under of magnetic field created by magnet 2 is in upper position (left cylinder). The upper position of the cylinder ensures that its channels overlap the channel through which hot flue gas moves. Hot gas enters the piston through transverse channels, heating it, and is removed to atmosphere. Piston heats to Curie point temperature and loses ferromagnetic properties. The magnetic interaction force stops acting on the piston, and it starts to move downward under the action of the prevailing gravity force. At that piston rotates crankshaft 3 through the traction. At the same time the right piston goes up. It caused by the fact that it had previously heated and dropped down, cooled down from the air passing through it and restored its magnetic properties. In doing so, it rotates the crankshaft in the same direction.

The piston is cooled by the following processes. Piston, which stands in lower position with its channels closes the channel through which cooling air is supplied. Hot gas access to piston channels is not possible through its upper surface, which should be heat-insulated. The pistons change its position. Cooling air now passes through the left piston and flue gas goes through the right piston. Crankshaft 3 turns to operate generator. The cycle is repeated. Air that cools the piston heats up and enters the engine. Engine flue gases are utilized in your device. Thus, additional recovery of the thermal energy is carried out. In addition, after calculations, the scheme can be supplemented with recuperative heat exchangers.

6. Calculation the engine efficiency (method)
To determine the engine efficiency the unknown values are (taking into account the given structures and figure 7): gas temperature at output $t_{ou}^{gas}$ (and specific heat capacity at output $c_{ou}^{gas}$), air temperature at output $t_{ou}^{air}$ (and specific heat capacity at output $c_{ou}^{air}$).
Then we must calculate the energy balance. Input energy $E_{in}$, W:

$$E_{in} = Q_1 = h_{gas}^{in} - h_{gas}^{out} = G_{gas} \cdot (t_{gas}^{in} \cdot c_{gas}^{in} - t_{gas}^{in} \cdot c_{gas}^{in})$$

Output energy $E_{out}$, W:

$$E_{out} = Q_2 = h_{air}^{out} - h_{air}^{in} = G_{air} \cdot (t_{air}^{out} \cdot c_{air}^{out} - t_{air}^{in} \cdot c_{air}^{in})$$

Energy efficiency is determined by the difference between input and output energy $A$, W:

$$A = E_{in} - E_{out} = G_{gas} \cdot (t_{gas}^{in} \cdot c_{gas}^{in} - t_{gas}^{in} \cdot c_{gas}^{in}) - G_{air} \cdot (t_{air}^{out} \cdot c_{air}^{out} - t_{air}^{in} \cdot c_{air}^{in})$$

7. Conclusion

At present, the characteristics of devices using the above effect are not quite effective. This is due to both a small amount of research in the field and a lack of funding, as well as a lack of industrial research capacity.

One of the main tasks of these installations’ application is search optimal technological solutions, and choose of a right constructions and materials for the engine aslo.

Acknowledgments

The article was written with the financial support of the Russian Federation President grant for state support of young Russian scientists - candidates of sciences MK-2369.2020.8 (Arrangement № 075-15-2020-159).

References

[1] Getman VV, Lezhneva N.V. Metody utilizatsii teploty ukhodyashchikh gazov ot energeticheskikh ustanovok // Bulletin of Kazan Technological University. 2013. No. 12.

[2] Cherezov G.V., Golovin S.V. Osnovnye napravleniya modelirovaniya sistem utilizatsii teploty v sostave kompleksnykh energoistochnikov na geologo-razvedochnykh rabotakh // Scientific statements of BelSU. Series: Natural Sciences. 2016. No. 11 (232).

[3] Solomin I.N., Daminov A.Z., Kamalov R.F., Sadykov R.A. Utilizatsiya i preobrazovanie nevostrebovannoi teplovoi energii v teplosnabzhayushchikh sistemakh ot raionnykh kotel'nykh // Izvestia KazGASU. 2013. No. 4 (26).

[4] Yanchoshek L., Kuntz P. Organicheski tsikl Renkina: ispol'zovanie v kogeneratsii // Turbines and Diesels, 2012, No. 2. - P. 50-53.

[5] Yelsukov V.K., Pak G.V. Tekhnologii utilizatsii tepla dymovykh gazov i metodika rascheta ekonomicheskogo effekta // Transactions of Bratsk State University. Series: Natural and Engineering Sciences. - 2007. - T. 2. - S. 95-103.
[6] Enivatov A.V., Artemov I.N., Savonin I.A. Optimizatsiya teplovoi skhemy kotel'noi s utilizatorom tepla dymovikh gazov // IED. 2018. No. 1 (48).

[7] Shaposhnikov, V.V. Sravnenie effektivnosti teplovykh skhem i tsiklov PGU s vpryskom vodyanogo para iz kotla-utilizatora v gazovyi trakt [Electronic resource] / V.V. Shaposhnikov, B.V. Biryukov, A.V. Shaposhnikov // Modern problems of science and education. - 2015. - No. 2. - Access mode: www.science-education.ru/122-21208.

[8] N.N. Efimov, V.V. Papin, R.V. Bezuglov. Determination of Rotor Surfacing Time for the Vertical Microturbine with Axial Gas-Dynamic Bearings / Procedia Engineering. Vol. 150 (2016), p. 294-299, impact-factor Scopus 0,238, URL: http://dx.doi.org/10.1016/j.proeng.2016.07.006.

[9] N.N. Efimov, V.V. Papin, R.V. Bezuglov. Micro Energy Complex Based on Wet-Steam Turbine / Procedia Engineering. Vol. 150 (2016), p. 324-329, impact-factor Scopus 0,238, http://dx.doi.org/10.1016/j.proeng.2016.07.022.

[10] Pashchenko F.F., Torshin V.V., Krukovsky L.E. Sposob preobrazovaniya teplovoi energii v elektricheskuyu energiyu / Pat. 2379820 RF, IPC H02N 10/00 - No. 2008149416/06; declared 12/15/2008; publ. 01/20/2010, Bull. Number 2.

[11] Pashchenko F.F., Torshin V.V., Krukovsky L.E. Ustroistvo dlya preobrazovaniya teplovoi energii v elektricheskuyu energiyu / Pat. 2382479 RF, IPC H02N 10/00 - No. 2009108249/06; declared 03/06/2009; publ. 02/20/2010, Bull. Number 5.

[12] Mishchenko E.N., Mishchenko S.E., Shatsky V.V. Sposob preobrazovaniya teplovoi energii v elektricheskuyu i ustroistvo dlya ego osushchestvleniya / Pat. 2542601 RF, IPC H02N 10/00 - No. 2012151495/28; declared 11/30/2012; publ. 02/20/2015, Bull. Number 5.

[13] Mishchenko E.N., Mishchenko S.E., Larin A.YU. Ustroistvo dlya neposredstvennogo preobrazovaniya teplovoi energii v elektricheskuyu / Pat. 2620260 RF, IPC H02N 10/00 - No. 2015142594/06; declared 10/06/2015; publ. 04/10/2017, Bull. Number 10.

[14] Skiba, E.D. Analiz raboty teploobmennogo apparata pri zagryaznenii teploperedayushchei povrkhnosti / E.D. Skiba E.V. Kocharyan, V.V. Shaposhnikov // Energy Security and Energy Saving. - 2018. - No. 2. - S. 18-20.