Electricity generated from the low-temperature exhaust

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Crude oil is becoming rare, therefore expensive and consequently petrol and diesel as well. The latter is the basis of our daily mobility, until now without any serious alternative solution. The explosion of the Deepwater Horizon drilling rig [1] caused the death of eleven people and huge environmental contaminations. This event shows us the rising costs and risks of the oil production with unavoidable secondary damages for human and nature. Nevertheless, even modern engines convert only about one third of the chemical energy of the fuel into movement. The rest is wasted to the environment. To overcome this problem, a more efficient usage of petrol and diesel in the traffic sector is obligatory and leads to enormous efforts in the research and development. A system that recovers and converts heat from the exhaust to electricity is one feasible solution.

BMW is working on a thermoelectric generator operating by use of the inverse Peltier effect [2]. However, until now only about one percent of the heat is converted into electricity, the predicted electrical power will be 300 Watt. The scientists research for new alloys which are useful for the Peltier technology and so to increase the coefficient of performance (COP). The company Amovis works on a different principle, which is similar to the steam engine [3]. A working agent is evaporated with the exhaust heat. The pressure rises until a turbine can be operated. After this the cooling water is used to liquefy the vapor and a pump brings it back to the evaporator. The use of shape memory alloys (SMA) is relatively new. Researchers at General Motors are trying to connect the effect shape changes due to temperature changes to a generator [4]. The advantage of such SMA is their high force and power density.

The company FOX Autotechnik [5] develops in cooperation with the research institute ILK Dresden [6] thermal engines for waste heat recovery as well. According to the exhaust temperature FOX Autotechnik and ILK Dresden distinguished between two concepts. For higher exhaust temperatures up to 900°C (1650°F) a system comparable to a Stirling motor will be available, that operates according to a novel pulse tube principle [7]. For medium exhaust temperatures between 300 and 500°C (570 to 930°F), for example of diesel engines, another working principle is foreseen to recover the exhaust heat. For this working principle, schematically shown in Fig. 1, the patent is already pending.

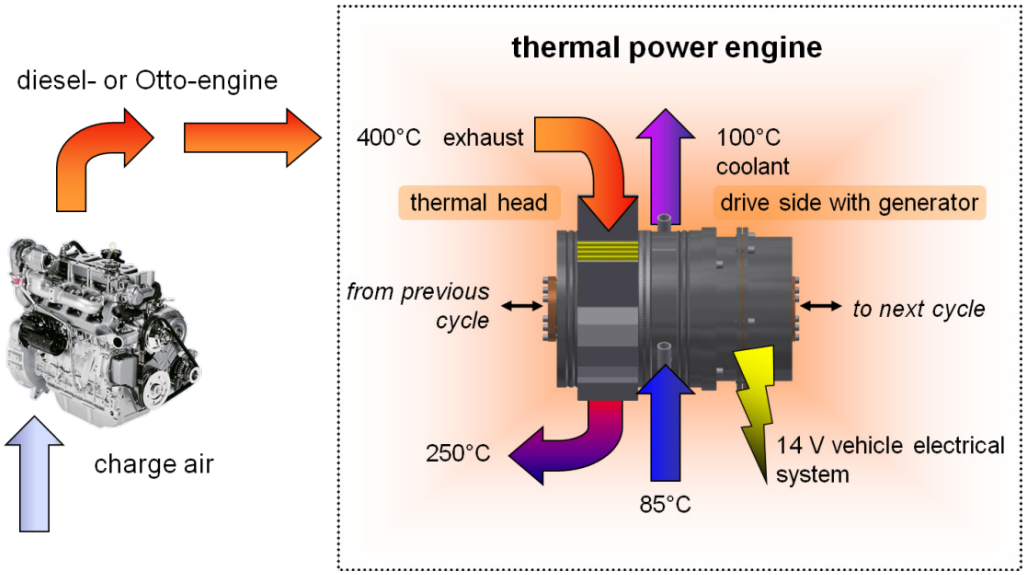

Figure 1: concept and principle of the thermal engine

[1] http://en.wikipedia.org/wiki/Deepwater_Horizon_explosion
[2] http://www.themotorreport.com.au/23040/bmw-and-nasa-teaming-up-to-devise-regenerative-exhaust-system
[3] http://www.amovis.de/de/kompetenzen.htm
[4] http://www.popularmechanics.com/cars/alternative-fuel/news/4344643
[5] http://www.fox-sportauspuff.de/
[6] http://www.ilkdresden.de/
[7] http://www.ilkdresden.de/fileadmin/user_upload/img_projekte/00_Kryotechnik/Waermekraftmaschinen/Publikation_Fox_ILK_EN.pdf

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Both systems have no moving elements in the hot part of the engine, the part which is connected to the exhaust line. So the problems of piston guidance, sealing and lubrication at the high temperatures of the exhaust gas are avoided.

parameter	prototype
temperature demand (exhaust)	300 to 500°C (570 to 930°F)
cooling water temperature	85 to 110°C (185 to 230°F)
waste heat demand	15 kW (at 400°C (750°F))
electrical power	2 kW (at 400°C (750°F))
operating frequency	260 Hz
working fluid	propane
operating pressure	30 bar (435 psi)

Table 1: general technical data of the prospective prototype

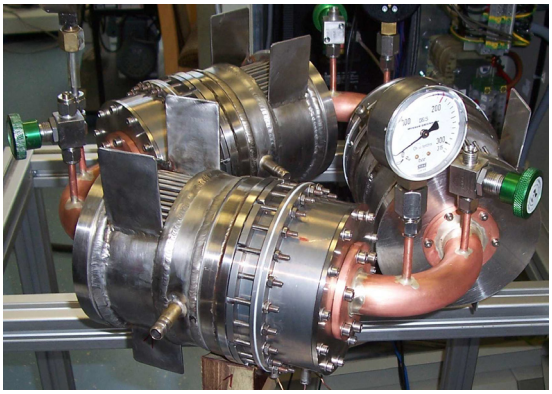

Figure 2: Thermal engine, assembled

The machine operates according to a 3-cycle alpha type Stirling [8]. A working fluid alternates between the supercritical state in the cold part and the state as superheated vapor in the hot part of the machine. Fig. 2 shows the assembled thermal engine with thermal head and generator.

The main advantages of this innovation are:

1. The generator output with a membrane piston leads to an almost maintenance free and high reliable system. The release of energy is only electrical.
2. The high volumetric power density of the novel thermodynamic cycle with its special working fluid implies a compact design. The integration in an existing exhaust line is consequently possible. The weight of the experimental model is 36 kg, with potential for significant reduction in weight.
3. For the full load operation the predicted reduction of gasoline is about 5 %. In case of partial load up to 15 % of gasoline can be saved, due to the support for the dynamo machine.
4. Because of the low heater temperature between 200 and 500°C it is possible to recover up to 40 % of the total exhaust energy. For the car application the COP (coefficient of performance – electric energy to exhaust energy) is about 10 %. Concerning a larger power range, that means the usage of the system in trucks, trains or ships, the COP could reach values up to 30 %.

Figure 3: Integration of the thermal engine in the exhaust gas system

The general technical data of the experimental model are shown in Tab. 1. The integration in the exhaust system is pictured in Fig. 3. For a better visibility, the insulation of the exhaust lines is dismantled. Cooling water supply will be provided via flexible hoses.

At the end of the project extensive experience for the design and manufacturing of thermal engines are available. Ergo, one more solution exists for an efficient use of the rare resource oil. The compact assembly and an almost free-maintenance operation are the basis for a future mass product. The experimental model will deliver an electrical power of 500 W.

The authors are thankful to Thomas Jande, Steffen Richter and Ulrich Zerweck from ILK Dresden for their active assisting in assembling and testing of the experimental model.

[8] http://en.wikipedia.org/wiki/Stirling_engine

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