WASTE HEAT RECOVERY IN HVAC SYSTEMS USING A STIRLING ENGINE

1. Abstract

Today still many people take natural resources for granted and waste precious energy. The results of such carelessness are devastating. However, the need for sustainable and renewable development has been proven and the world is slowly starting to turn around towards those ideas. Unfortunately, what holds us back are economical factors. In order to counter this problem, we need tools that are ecological and efficient, both economically and mechanically. A simple and effective solution to this world wide problem is the Stirling engine. This type of engines can take any kind of thermal energy and turn it into mechanical or electrical one. Such an engine can even use waste heat, giving us a ecological, emission free, sustainable and cheap energy. The objective of this research is to optimize Stirling engines and lead to their commercialization, particularly in HVAC systems.

2. Introduction

Any practical process of power generation (e.g. electrical, heat, etc.) is accompanied by losses along the way. Energy dissipation occurs during transport, generation, use, and it is inevitable. In addition to that, we deliberately throw away a large amount of energy in the form of heat. The reason for wasting it is mainly because we cannot find an efficient way to use it, or it is too expensive to do so.

For instance, air conditioning systems expel in the atmosphere heat that is gathered from the buildings. Not only is this energy rarely used but also large amount of electricity is required to expel it. What if instead of wasting all this power, we could use it? Finding a way to utilize waste energy will increase the efficiency of the power generation and thus lower its cost. One way of doing so, using the previous example, is to use the unnecessary heat to warm up water for domestic use. In reality this is rarely done (particularly in Bulgaria), because it increases the overall cost of the system. A cheap and efficient solution can solve these types of problems. Since Bulgaria cannot afford to invest enough, cheap, reliable and ecological solutions are required. This is exactly what this project proposes.

3. Energy loss problem in HVAC systems

People have always been aware of the negative effects of energy losses in a system. Higher losses lead to higher production in order to achieve a steady output and this leads to higher costs of operation. Since most of the input energy comes from fossil fuels (whether from a burning process or electrical power), increased consumption leads to increased pollution. Thus, it can easily be concluded that energy losses contribute to global warming. That is why our goal is to reduce them as much as possible.

All heat-power conversion systems produce waste heat, which can attain significant proportions. The waste heat fraction depends on the conversion technology. The more waste heat that can be utilized for some useful purpose (and consequently requires less heat to be rejected), the better economy can be achieved. The best solution to avoid discharge in the atmosphere or in the

hydrosphere is cascade use. This consists of a chain of applications with stepwise decreasing temperatures.

3.1 Examples of waste heat in various HVAC systems:

- Air conditioning systems, during the cooling period (summer), expel large amounts of heat captured from the building. Typically it is hot water with temperatures around 35-40˚C.
- Hot gasses from a burning process. Whether it we are burning fossil or biofuel, the exhaust gases are with a temperature around 300˚C. These gases are released in the atmosphere, with little or no utilization of their energy.
- Excess heat from solar collectors. Solar collectors used for production of hot water for domestic needs, with temperatures around 60˚C often work until this temperature is reached. These systems leave large amounts of unutilized energy, since the peak production is usually during the lowest consumption.

Striving for an ecological future, it is vital to increase two indicators. One is improving performance per resource input or increasing resource productivity, which expresses the economic added value. The other is eco-efficiency, which indicates improved performance per environmental impact or increased added economic value during the product life cycle.

The realization of this project can contribute to reducing emissions, increasing efficiency and reducing costs in HVAC systems. By doing so we can create sustainable and cost-effective systems without compromising output quality.

4. The Stirling engine as a solution

4.1. Stirling engine principle

A Stirling engine is a device that converts heat energy into mechanical power by alternately compressing and expanding a fixed quantity of a working fluid at different temperatures. The Stirling engine is noted for its simplicity, quiet operation and the ease with which it can utilize what would otherwise be wasted heat. Compared to internal combustion engines, the Stirling engine is an external combustion device where the cycle medium is not exchanged during each cycle, but remains within the cycle whilst the energy driving the cycle is applied externally.

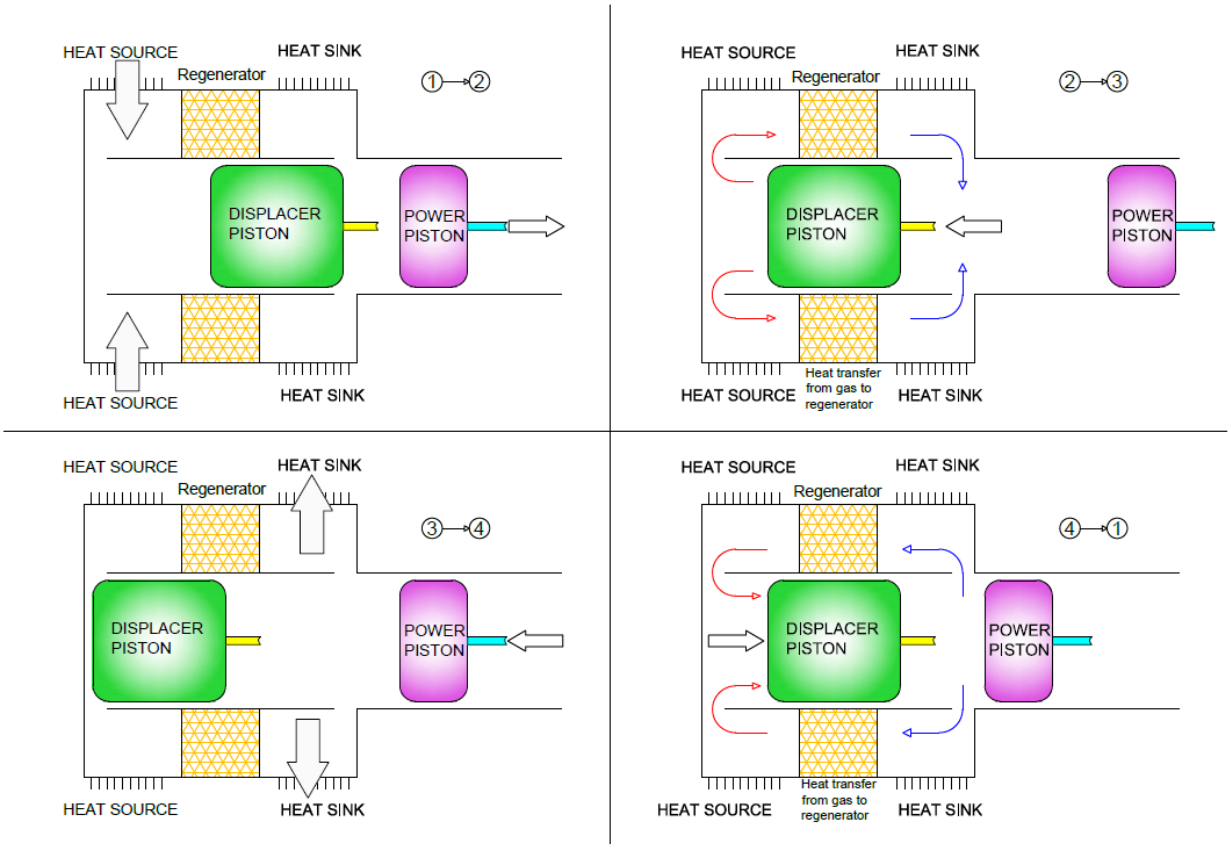

Fig. 1: Basic concept of a Stirling engine.

The Stirling engine technology is on the verge of commercialization. For this reason almost no statistical data on reliability, availability or prices is available. Since Japan is the country that invests the most in renewable energy, for the past decade many working prototypes of such engines have been developed there [6] [7] [8]. This is what makes it the best place for this project to be realized.

4.2. Ecological benefits

The first most noticeable benefit of the Stirling engine is that, the engine itself does not produce any emissions, since there is no burning process involved. Also the work fluid is not an environmental issue, since it can be Hydrogen, Helium, or even air. The "green" nature of the engine is a big advantage, but what is more important is that, by reducing heat losses, we indirectly reduce emissions:

The energy that is produced in a particular process (electrical, mechanical, heat, etc.) is never equal to the amount of energy that is consumed:

$$Production = Consumption + Losses$$

Lowering the consumption is not an easy task to achieve. A much simpler objective is to reduce the losses. By doing so, we decrease the production of energy. Since almost all of the energy we produce comes from burning fossil fuels, decrease in production leads to decrease in pollution.

For example if we use a Stirling engine to produce electricity from the waste heat generated by a building's HVAC system, we do not reduce the electrical consumption inside the building, but we reduce the electricity that we buy from the electric company.

4.3. Economical benefits

Facing a global energy crisis, we need to conserve the little resources that are left and steadily turn to more sustainable and renewable ones. The fact that the Stirling engine utilizes heat energy that is otherwise "thrown away" means that no fuel is needed and, therefore, it has zero *operation cost*. Furthermore, the simplicity of the engine allows for minimal or no maintenance. Overall, there are no expenses required during the operation, cutting it down only to the initial investment, that is the price of the engine itself. The period that is required for the engine to fully pay off itself, can be easily calculated, and from that point forward it becomes profitable.

Following the previous example, the use of Stirling engines reduces the costs for electricity for the whole building. From an economical point of view, the building (or the HVAC systems) has higher operational efficiency.

4.4. Other benefits and disadvantages

One of the great advantages of these engines is that, they can work on any heat source and sink. A Stirling engine can be installed in any systems where a temperature difference between two fluids can be established. A heat source/sink can even be the surrounding air. Not only their simplicity allows them to be virtually eternal, but they produce very little noise during operation.

All of the above factors give the Stirling engine an enormous advantage, since they can be installed almost anywhere. The only limitation is their size and price. Some people consider the overall low efficiency of the Stirling engine a disadvantage, but if your source of energy is "free," all that matters is the price of the engine itself.

The purpose of this research is not to create and develop a Stirling engine from scratch, but rather refine and modify an existing one, so that it could match the requirements of various HVAC systems. This approach is much better and cheaper and can yield results faster. Another advantage of the project is the fact that an extensive research in the area has been conducted for many years, especially in Japan. This technology is one the verge of commercialization, further research and development can eventually accomplish that. The results from commercial products can help countries, such as Bulgaria, that strive for a more ecological and sustainable development, but do not have the necessary capital to do so. These products will also significantly benefit the countries that are strongly investing in their "green" future – in particular, Japan.

4.5. Practical application of the Stirling engine

In HVAC systems many examples for heat sources and sinks can be found. Below is a list of the ones that are very common in Bulgaria:

- Excess heat from air conditioning systems, during the cooling period (summer). Normally this is hot water is with temperatures around 35-40˚C. This heat can be used for preheating domestic hot water, but it is rarely done. Therefore, this type of waste heat is a very good heat source for a Stirling engine, since the temperature and flow are relatively constant during the operation.
- Exhaust gasses from a burning process. With a temperature around 300˚C these gases contain a lot of unutilized energy. Taking in consideration that such devices are mostly

operated during winter periods, this gives us the opportunity to use the cold outdoor air as a heat sink. Unfortunately there are many domestic heating systems in Bulgaria that use diesel or wood as their primary fuel. Converting to more sustainable and renewable systems is an expensive investment. That is why, if supported by a cheap Stirling engine the payback period can be decreased significantly.

- Excess heat from solar collectors. Solar collectors used for production of domestic hot water, with temperatures around 60˚C often work until this temperature is reached. These systems leave large amounts of unutilized energy, since the peak production is usually during the lowest consumption. Solar power is gaining more and more popularity in Bulgaria. However such inefficient use of these systems can not yield much or any economical benefits. This is caused by the fact that the lifespan of cheapest solar collectors (which are the most common type used) is usually less than the payback period.
- Cold water that is heated for domestic purposes can also be utilized. With temperature of around 10˚C, it can be used as a heat sink. Using it for preheating domestic hot water, we lower the energy that is needed to reach the necessary consumption temperature.
- Another source of relatively hot water is the domestic hot water itself. After it has been used it is released in to the sewer. There are systems, that can separate it from the main sewer line, leaving relatively clean water. Subsequently, it is relatively simple to transfer that heat into a Stirling engine.
- Another example is the geothermal water used for recreational and medical purposes (e.g. spa). These rich in valuable chemical composition water, is extracted with relatively high temperature (about 80˚C). The temperature has to be lowered in order to be properly used. Some of the excess heat can be used for domestic water and space heating; however, there is still much unutilized heat. Both the input and output (already used) geothermal waters can be used as a heat source, creating a cascade utilization of the geothermal energy.

5. Conclusions

The Stirling engine produces no emission what so ever and the energy that it uses is otherwise thrown away, possibly polluting the environment. Undoubtedly the Stirling engine is an ecologically friendly solution, but it can as well be very economically efficient. Producing energy from a relatively “free” source, leaves only one problem – the cost of the device itself. However if we consider that these type of engines are virtually eternal, then the problem turns into a question: how long will it take to pay off? The need for the commercialization of such technology exists and the benefits from it will be noticeable.

We are facing depletion of organic fuels and price increase of raw energy. The Stirling engines provides a long term, ecological and economical solution. The technology and the idea of the engine aren’t new. Research and development in this area has been done for many years. Since we are on the verge of commercialization of that technology, little effort and finance is required to do so. That is why there is no need to develop new engines - refining existing ones is an effective solution.

Having vast “intellectual pool,” experience and resources in technological development, Japan stands as one of the best in that field. Much of the research on Stirling engines is done at the universities of Tokyo, Nagoya; Tokyo Institute of Technology and others. That is why Japan is found to be the best place for this project to be realized. Little efforts and resources are required, but upon its success much will be achieved and the benefit will be global.

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