2581-4575

International Journal For Recent Developments in Science & Technology

Crossref

A Peer Reviewed Research Journal

ENERGETIC AND ECOLOGICAL BENEFITS OF HEAT PUMP APPLICATION IN ENERGY TRANSFORMATION SYSTEMS

[1]MULABAGAL SANDEEP, [2]VASILI SRINIVAS

[1]Asst.Professor, Department of Mechancial Engineering, Malla Reddy Engineering College (Autonomous), Maisammaguda(H), Gundlapochampally Village, Secunderabad, Telangana State – 500100

[2]Assoc.Professor, Department of Mechancial Engineering, Malla Reddy Engineering College (Autonomous), Maisammaguda(H), Gundlapochampally Village, Secunderabad, Telangana State -500100

Abstract

In 1900, Nikola Tesla published a paper: *The problem of increasing human energy*, stressing that generating electricity from burning of coal we would be destroying material, which would be a barbarous process. This message is still vitally important, and one method to mitigate the barbarous effects is e.g. application of heat pump. Its benefits are twofold: economical and ecological. Heat pump reduces fuel consumption and lessens the burden on the environment through combustion products. As example, we have quantified its application in the area of heating, but the results obtained are extendable to any energy system. The most significant parameters are the efficiency of the energy conversion process and the COP of the heat pump. When the product of these two parameters is equal to one, part of energy losses, occurring in the energy conversion process which is associated with the heat pump application, can be completely utilised by the heat pump as useful heat. This is of paramount importance for reduction of energy conversion losses and protection of the environment. In general, both the fuel consumption and amount of combustion products decrease with increasing COP, that is, with increasing evaporation temperature and/or decreasing condensation temperature of the working fluid used in the heat pump.

Keywords: Heat pump, Heating, Environment, Energy losses, Energy balance

1. Introduction

Limited resources of fossil fuels and pollution of the environment have strengthen the discussion in the last years on handling the energy resources gently, calling for more efficient energy transformation and rendering other energy kinds accessible. Due to the imperfection of devices and thermodynamic limitations arising from technological restrictions, the efficiencies of energy conversion processes are still very low. In 1996, J. H. Ausubel [1] asked the question: *Can Technology Spare the Earth*? His analysis suggests that technology could restore the environment, even as population grows, if efficiencies of energy conversions correspondingly evolved. Meanwhile, numerous studies have appeared, dealing with the interactions within the triangle

International Journal For Recent Developments in Science & Technology
2581-4575
Crossref
A Peer Reviewed Research Journal

society-productionenvironment, thereby discussing future developments in this area, see e.g. [2]. The analysis is mostly based on the exergy concept [3, 4]. As shown below, this concept is not indisputable, particularly regarding the environment as the reference system. In order to protect the environment from harmful technical wastes, several ideas have been developed and tested under real conditions. One of them is the application of heat pumps which should reduce the primary energy required for process operation. However, despite the extensive research, there are apparently no papers in the literature stressing economical and ecological benefits of heat pump application. The same is true regarding the interaction of heat pump efficacy and energy losses in conversion processes of primary energy. Also detailed comparisons of different heating systems are missing in literature, a paper by Acikkalp and Aras [5] being an exception, to some extent. The authors compared a natural gas boiler with a heat pump heating system. They found the heat pump system to be more efficient, but their statement, the heat pump would not release CO_2, does not generally hold.

2. The Scope of the Present Paper

In this paper we quantify benefits of heat pump application in energy conversion systems (heating) regarding primary energy requirements for its operation and environmental impact. We compare some heating possibilities with each other assuming various sources of primary energy and different processes of its transformation. In particular we include following cases:

1. Combustion of a fossil fuel (e.g. coal), alternatively biofuel, for direct heating.
2. Conversion of electric energy into heat, whereby electric energy may stem from various sources of primary energy.

3. Environment and its Protection

The term environment is frequently used in science and everyday life, but a precise definition of its meaning is still vague. As environment we consider the space of the Earth occupied by humans. This is the upper most layer of the lithosphere and the lower most layer of the atmosphere. Taking the thicknesses of these layers to be some 10 km each, and the radius of the Earth of 6370 km, the volume of the environment would be 10 billions of cubic kilometres ($10.2 \cdot 109$ km3). This spherical shell corresponds to a 0.0785 mm thick film covering a sphere of 50 mm in diameter. The size of the environment becomes more impressive if its volume is divided by the world population, at present more than 7 billion people; this allows about 1.4 km3 per capita, which reduces down to about 0.42 km3 if the sea surface area is disregarded. The assumed thickness of the atmospheric layer may appear to be too small, but the situation would change only by a factor of about 5, if we extend the margin of the outer layer up to von Karman's line (100 km) and completely include the biosphere.

Our environment is exposed to many internal and external influences. The external influences arise from celestial bodies, mainly from the Sun, and manifest themselves as radiation fluxes. Man-made impacts are associated with flows of energy

International Journal For Recent Developments in Science & Technology
2581-4575
Crossref
A Peer Reviewed Research Journal

and matter sustained by our activities. As far as external effects like thermal radiation are concerned, long term variations of radiation fluxes (Earth's insolation) have been modelled in detail by Milankovic [6] taking into account variations of the main degree of freedom of the Earth. Meanwhile, his theory, well-known as the long-term Milankovic cycles, has been largely validated. The external fluxes may amplify terrestrial processes and unpredictably affect the environment.

4. Illustration of Heat Pump Principle

4.1. The Working Principle

The operation method of heat pump follows from the second principle of thermodynamics stated in 1854 by Clausius [18]: Es kann nie Wärme aus einem kälteren in einen wärmeren Körper übergehen, wenn nicht gleichzeitig eine andere damit zusammenhängende Änderung eintritt, or Heat can never pass from a colder to a warmer body without some other change, connected therewith, occurring at the same time. (Translation by Clausius himself, in 1856 [19]).

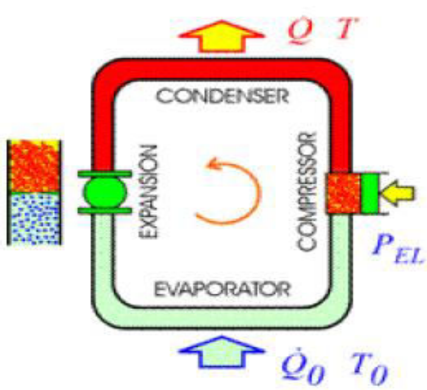

Figure 1: Schematic of a heat pump, from [20], modified.

The constraint, wenn nicht gleichzeitig eine and ere damit zusammenhängende Änderung eintritt, allows heat transport from cold to warm body if simultaneously a reverse process occurs, by which heat flows from warm to cold body. Heat pump accomplishes these processes, Figure 1. It takes the heat Q&0 from a body of temperature T0 and transports it to a body of the temperature T > T0 ; it pumps heat from lower to higher temperature, hence the name **heat pump**. The simultaneous reverse process is associated with the generation of its operation energy in a thermal power plant, for instance.

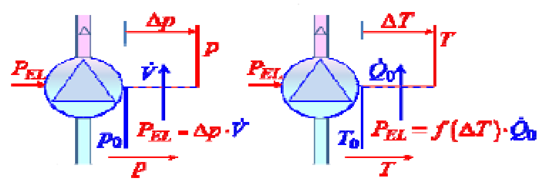

Figure 2: Heat pump in compression with fluid pump: Heat flow rate $\dot{Q}_0$ corresponds to volume flow rate $\dot{V}$, Δp and ΔT are resistances to be surmounted by respective flows [21].

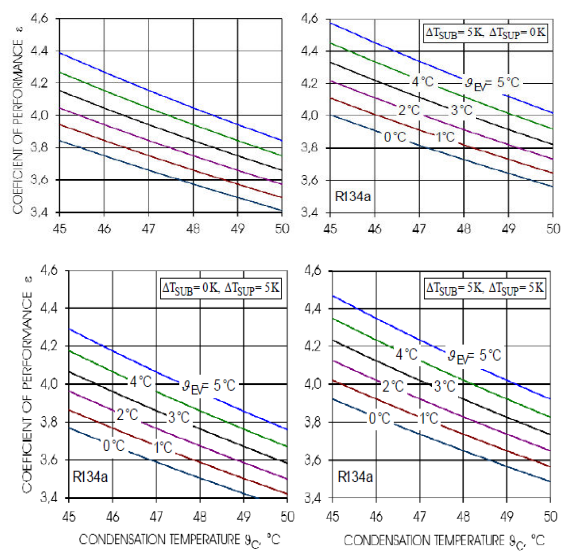

Figure 3: Coefficient of performance ε of heat pump calculated by Eq.(2) for the parameters displayed on diagrams

2581-4575
International Journal For Recent Developments in Science & Technology
Crossref
A Peer Reviewed Research Journal

5. Energetic and Ecological Evaluations

Next, an evaluation of different heating modes is undertaken under basically identical conditions and the results obtained are compared with each other. As example of combustible fuels, only combustion of coal is considered. The considerations remain basically the same if gas or biomass is used instead of coal. Regarding the environment, only the gaseous combustion products are considered. The chemical composition of coal usually depends on its origin and varies in wide boundaries. Some properties of the coal, chosen for the calculations, are listed in Table 1. With the displayed data, the quantities required for the analysis are calculated as follows.

5.1. Direct Combustion Heating Mode

Figure 4 illustrates a direct combustion heating mode. Combustion is assumed to occur completely according to stoichiometric relations. Only carbon, hydrogen and sulphur undergo combustion reactions, producing carbon dioxide, sulphur dioxide and water vapour which affect the environment. Nitrogen is viewed as inert in this analysis.

Table 1: Mass fractions of combustible coal species and combustion products, 1 $nm^3 = 22.414\ m^3/kmol$ at 0 °C and 101.325 kPa

Species k	Mass fraction ξ_k $kg/kgFuel$	Molar mass M_k $kg/kmol$	Comb. reaction	Reaction enthalpy Δh_k $MJ/kmol$	Reaction enthalpy Δh_k kJ/kg	Combustion products (gas) Formula	Combustion products (gas) $\psi_k = \xi_k / M_k$ $kmol/kgFuel$	Combustion products (gas) $nm^3/kgFuel$
Carbon C	0.70	12	$C + O_2 \rightarrow CO_2$	-393.5	-32791.7	CO2	0.0583	1.3075
Hydrogen H2	0.06	2	$H_2 + (1/2)O_2 \rightarrow H_2O$	-285.9	-14295.0	H2O	0.03	0.6724
Sulphur S	0.02	32	$S + O_2 \rightarrow SO_2$	-296.6	-9268.8	SO2	0.000625	0.0140
Total	0.78	-	-	-	-	-	0.088925	1.9939

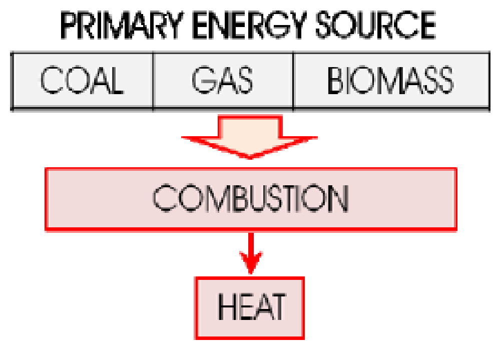

Figure 4: Direct combustion heating mode

5.2. Indirect Combustion Heating

With indirect combustion heating, fuel is burned in a thermoelectric power station and the electric energy is then directly transformed into heat (Joule-heating), or is used for operation of a heat pump. Figure 5 illustrates these heating modes. Next, fuel consumptions and the impacts on the environment of these heating modes is calculated and compared with those of direct combustion heating.

5.2.1. Heating by Using of a Heat Pump

The electric energy required for heat pump operation is provided by a thermal power plant that uses the coal of the same quality that has been taken for direct combustion heating, see Table 1. The consumption of coal and production of combustion gases obey the equations stated above.

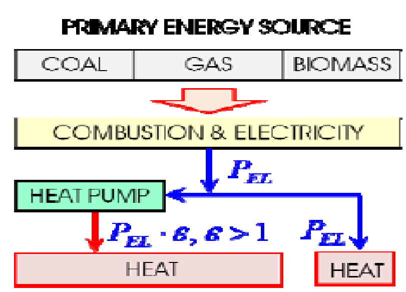

Figure 5: Heat pump heating or Joule heating?

2581-4575
International Journal For Recent Developments in Science & Technology
Crossref
A Peer Reviewed Research Journal

6. Heat pump and energy conversion losses

The system of lower temperature with heat pump application is usually our surroundings which absorb the energy losses accompanying energy conversion processes, e.g. in thermal power plants. Now, the question before us may be started thus: To what extent can heat pump convert these losses in useful energy? An answer to this question is of essential importance with regard to overall energy balance and the protection of the environment. With reference to Figure 10, it may be treated by starting from the equation

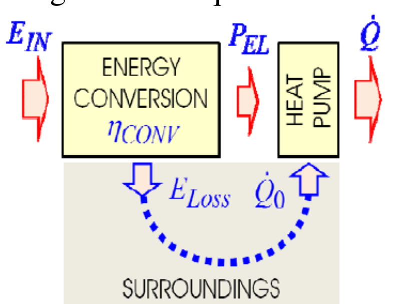

Figure 10: Losses of energy conversion feed heat pump with low temperature energy.

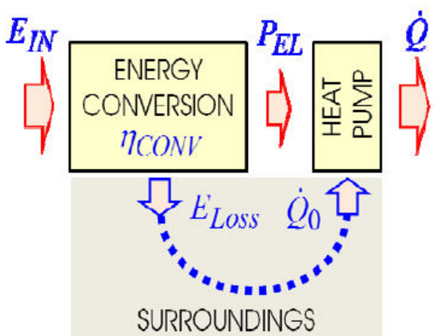

Figure 10: Losses of energy conversion feed heat pump with low temperature energy.

7. Conclusion

In 1900, Nikola Tesla stressed that generating electricity from burning coal we would be destroying material, and this would be a barbarous process. This warning equally applies today, whether by direct combustion of fuel for heating of buildings, or by production of electricity. The combustion products are pivotal regarding the environment and its protection. In this context, several ideas have been put forward and tested with various outcomes. In the present paper we have quantified the economical and ecological benefits of heat pump application in energy transformation and transport processes, assuming its operation energy to stem from different sources of primary energy. Heating of buildings is adopted as an example of the analysis. Direct combustion heating is used as basis for comparison purposes. From the obtained results, the following main conclusions may be drawn:

1. When the heat pump operation energy stems from a thermal power plant, benefits of heat pump's application are of particular importance. Heat pump reduces both consumption of fuel and impact of combustion products on the environment.
2. If the heat pump is operated from blue energy sources (solar, hydro-, geo- and aero-energy), and the blue energy does not cover the energy demands, it reduces indirectly the fuel consumption and protect the environment.
3. The economical and ecological benefits of heat pump application depend on its COP. The larger the COP the larger its effects. This requires a high evaporation temperature combined with a low condensation temperature.

International Journal For Recent Developments in Science & Technology
2581-4575
Crossref
A Peer Reviewed Research Journal

4. A simple relation is deduced which answers the following question: Can heat pump utilise the energy losses occurring e.g. in thermal power plant while generating electric energy required for its operation? This relation demands that the overall plant efficiency, multiplied by the COP of the heat pump, be equal to, or larger than, one. Because heat losses are absorbed by the surroundings and the heat pump takes heat from the surroundings, application of heat pump can reduce thermal misbalance of the surroundings arising from the man-made processes.

References

[1] Ausubel J. H. : Can Technology Spare the Earth? American Scientist Magazine 84 (1996)2:166-178. http://phe.rockefeller.edu/sparetheearth/

[2] Hammond G. P.: Engineering sustainability: thermodynamics, energy systems, and the environment, Int. J. Energy Res. 2004; 28:613–639; http://dx.doi.org/10.1002/er.988

[3] Wall G.: EXERGY – AUSEFUL CONCEPT, Göteborg 1986 3rd edition, www.**exergy**.se/ftp/thesis.pdf

[4] Szargut J. Exergy method: technical and ecological applications. Ashurst, UK: WIT-press; 2005. Subramanyam Pavuluri https://orcid.org/0000-0002-2703-2358

[5] Acikkalp E., Aras H.: Comparing Geothermal Heat Pump System with Natural Gas Heating System, World Renewable Energy Congress – Sweden, 8–13 May, 2011,Linköping, Sweden.

[6] Milankovc M.: Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem. Belgrad, 1941; *Canon of insolation and the ice-age problem.* English translation by the Israel Program for Scientific Translations, published for the U.S. Department of Commerce and National Science Foundation, Washington, D.C.: 633 S., 1969

[7] Brodianski V: Earth's available energy and the sustainable development of life support systems. Theories and Practices for Energy Education, Training, Regulation and Standards, from Encyclopedia of Life Support Systems (EOLSS). Online encyclopedia: http://www.eolss.net. Retrieved May 19, 2005.

[8] Thomson W.: Electrical Units of Measurement, Popular Lectures and Addresses, London, 1889-91, Vol. I, 73.

[9] Kuhn T. S.: The Function of Measurement in Modern Physical Science, *Isis* **52** (1961) No. 2, 161-193.

[10] Dewulf J., Van Langenhove H., Muys B., Bruers S., Bakshi B. R., Grubb G. F., Paulus D. M., Sciubba E.: Exergy: Its Potential and Limitations in Environmental Science and Technology, *Environ. Sci. Technol. 42* (2008), 2221–2232; http://dx.doi.org/10.1021/es071719a

[11] R. P. Feynman, Leighton R.B., Sands M.: *The Feynman Lectures on Physics*, Vol. I; Reading, Massachusetts: Addison-Wesley Publishing Company, 1963.

[12] Gaudreau K., Fraser R. A., Murphy S.: The Tenuous Use of Exergy as a Measure of

Resource Value or Waste Impact, *Sustainability* 2009, 1, 1444 – 1463; http://dx.doi.org/10.3390/su1041444

[13] Tesla N.: *The problem of increasing human energy*, Century Magazine, June 1900. http://www.kocaeli.org/forum/Attachments/TheProblem OfIncreasingHumanEnergy.pdf

[14] Tesla N.: *Our future motive power*, New York Times, Nov. 8, 1931, also: Everyday Science and Mechanics, December 1931. http://www.tfcbooks.com/tesla/1931-12-00.htm