EXERGETIC STUDY OF THE IRREVERSIBLE PROCESSES OF COMPRESSION AND EXPANSION

Marcel DRĂGAN, Krisztina UZUNEANU, Gelu COMAN
"Dunărea de Jos" University of Galaţi,

ABSTRACT*:* As one of the fundamental purposes of the technical thermodynamics is to minimize entropy generation through improvements to thermodynamic design, the present paper provides a study on compression and expansion processes. By analyzing the irreversibility of compression and expansion processes we will identify the effect, cause and measures that can be taken to limit the generation of entropy and implicitly the destruction of exergy.
KEYWORDS: entropy, compression, expansion

1. GENERAL APRECIATIONS

In thermal machines, due to internal friction, the compression and expansion processes are irreversible.

This will either lead to additional mechanical work (compression processes) or to a decrease in the mechanical work produced (the expansion processes). In thermal machines, due to internal friction, the compression and expansion processes are irreversible.

This will either lead to additional mechanical work (compression processes) or to a decrease in the mechanical work produced (the expansion processes).

For these processes, the fundamental equation of exergy is written as:

$$\Delta e + l_t + e_D = 0 \quad [kJ/kg] \tag{1.1}$$

which will give the relation to further calculate the destruction of exergy:

$$e_D = -\Delta e - l_t \quad [kJ/kg] \tag{1.2}$$

By determining the variation of exergy,

$$\Delta e = i_2 - i_1 - T_0(s_2 - s_1) \quad [kJ/kg] \tag{1.3}$$

and the technical mechanical work,

$$l_t = -\int_1^2 di = i_1 - i_2 \quad [kJ/kg] \tag{1.4}$$

it will result in destruction of exergy specific to compression and decompression processes

$$e_D = T_0(s_2 - s_1) = T_0 \cdot s_{gen.} \quad [kJ/kg] \tag{1.5}$$

Fig. 1 illustrates the compression (a), and expansion processes (b), achieved at temperatures higher than the ambiental temperatures.

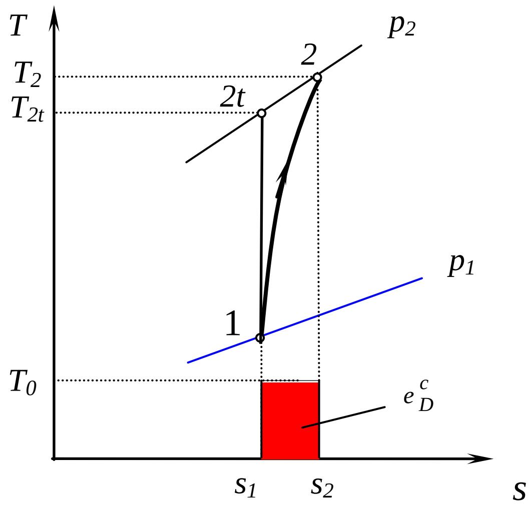

Fig 1.(a)

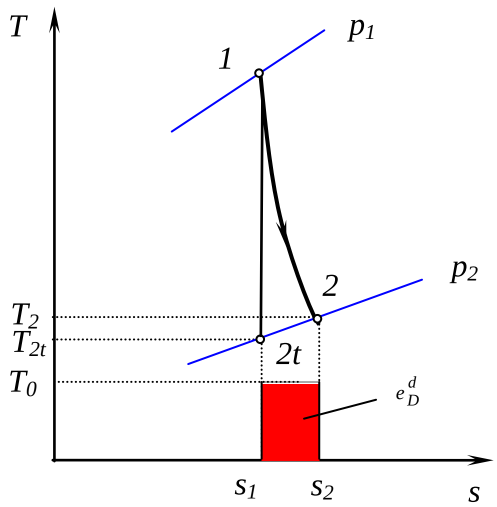

Fig. 1. (b)

If we consider the perfect gas working fluid, the entropy increase for these processes is expressed as:

$$s_2 - s_1 = \int_1^2 \frac{\delta q}{T} = \int_1^2 \frac{di - vdp}{T} = \bar{c}_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1} \quad [\text{kJ/kg K}] \qquad (1.6)$$

Because the entropy generated in the compression process, compared to the process of expansion, has characteristic elements that fundamentally differentiate it, we will analyze separately the two processes.

2. PROCESSES OF COMPRESSION

$\varepsilon = \frac{p_2}{p_1}$ - compression ratio,

$\eta_c = \frac{i_{2t} - i_1}{i_2 - i_1}$ - adiabatic compression yield

Depending on this, considering the theoretical (adiabatic) 1-2_t, compression, the temperature T_{2t} will be determined

$$\frac{T_{2t}}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} = \varepsilon^{\frac{k-1}{k}} \qquad (2.1)$$

In the relationship of adiabatic compression yield, considering c_p invariable with the temperature, we will get:

$$\eta_c = \frac{i_{2t} - i_1}{i_2 - i_1} = \frac{T_{2t} - T_1}{T_2 - T_1} = \frac{\frac{T_{2t}}{T_1} - 1}{\frac{T_2}{T_1} - 1} \qquad (2.2)$$

By using the relations (2.1) and (2.2), we will get the temperatures ratio,

$$\frac{T_2}{T_1} = 1 + \frac{\frac{T_{2t}}{T_1} - 1}{\eta_c} = 1 + \frac{\varepsilon^{\frac{k-1}{k}} - 1}{\eta_c} \qquad (2.3)$$

and the entropy relation generated during the compression process.

$$s_2 - s_1 = s_{gen}^c = c_p \ln\left(1 + \frac{\varepsilon^{\frac{k-1}{k}} - 1}{\eta_c}\right) - c_p \frac{R}{\bar{c}_p} \ln \varepsilon \quad [\text{kJ/kgK}] \qquad (2.4)$$

Knowing the expression of specific heat

$$c_p = \frac{k}{k-1} R \quad [kJ/kg\ K] \qquad (2.5)$$

we will have

$$\frac{R}{c_p} \ln \varepsilon = - \ln \varepsilon^{\frac{1-k}{k}} \qquad (2.6)$$

Introducing the relation (2.5) into (2.3), we will get the entropy generated during the compression process, the expression:

The following notations are used:

$$s_{gen}^c = c_p \ln \varepsilon^{\frac{1-k}{k}} + c_p \ln \frac{1 - \varepsilon^{\frac{1-k}{k}}}{\eta_c} \quad [\text{kJ/kgK}] \qquad (2.7)$$

Therefore, the exergy destroyed in the perfect gas compression process has the expression:

$$e_D^c = T_0 c_p \ln\left(\varepsilon^{\frac{1-k}{k}} + \frac{1-\varepsilon^{\frac{1-k}{k}}}{\eta_c} \right) \quad [kJ/kg] \quad (2.8)$$

The efficiency of the compression process is expressed using the exergetic yield as follows:

$$\eta_c^{ex} = \frac{\Delta e}{|l_c|} = \frac{|l_c| - e_D^c}{|l_c|} = 1 - \frac{e_D^c}{|l_c|} \quad (2.9)$$

3. *PROCESS OF EXPANSION*

$\beta = \dfrac{p_2}{p_1}$ - degree of expansion,

$\eta_d = \dfrac{i_1 - i_2}{i_1 - i_{2t}}$ - adiabatic expansion yield

Depending on this, considering the theoretical (adiabatic) expansion 1-2_t, the temperature T_{2t} will be determined.

$$\frac{T_{2t}}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} = \beta^{\frac{k-1}{k}} \quad (3.1)$$

In the relation of the adiabatic expansion yield, considering c_p invariable with temperature, we will get:

$$\eta_d = \frac{T_1 - T_2}{T_1 - T_{2t}} = \frac{1 - \frac{T_2}{T_1}}{1 - \frac{T_{2t}}{T_1}} \quad (3.2)$$

Using the relations (3.1) and (3.2), we will obtain the temperature ratio,

$$\frac{T_2}{T_1} = 1 - \eta_d \left(1 - \beta^{\frac{k-1}{k}} \right) \quad (3.3)$$

And the relation of the entropy generated in the expansion process.

$$s_2 - s_1 = s_{gen}^c = c_p \left[\ln\left(1 - \eta_d (1 - \beta^{\frac{k-1}{k}}) \right) \right] - R \ln \beta \quad [kJ/kgK] \quad (3.4)$$

Knowing the expression of specific heat,

$$c_p = \frac{k}{k-1} R \quad [kJ/kg\ K] \quad (3.5)$$

we can determine the equivalent relation,

$$\frac{R}{c_p} \ln \beta = -\ln \beta^{\frac{1-k}{k}} \quad (3.6)$$

Introducing relation (3.6) in (3.4), we will determine the entropy generated in the expansion process :

$$s_{gen}^d = c_p \ln\left[\beta^{\frac{1-k}{k}} - \eta_d \left(\beta^{\frac{1-k}{k}} - 1 \right) \right] \quad [kJ/kgK] \quad (3.7)$$

Use was made of the notations:

the exergy destroyed in the perfect gas expansion process has the expression:

$$e_D^d = T_0 c_p \ln\left[\beta^{\frac{1-k}{k}} - \eta_d \left(\beta^{\frac{1-k}{k}} - 1 \right) \right] \quad [kJ/kg] \quad (3.8)$$

The exergetic expansion yield will be:

$$\eta_d^{ex} = \frac{l_d}{|\Delta e|} = \frac{|\Delta e| - e_D^d}{|\Delta e|} = 1 - \frac{e_D^d}{|\Delta e|} \quad (3.9)$$

4. CONCLUSION

The study of the irreversibility of the thermodynamic compression and expansion processes allows to identify the factors that lead to the generation of entropy, and implicitly to the destruction of the mechanical work production capacity. The thermodynamic evaluation based on the destroyed exergy will allow for measures to improve the thermodynamic design.

5. REFERENCES

[1] Dragan M., Uzuneanu, K., Panait, T., Coman, G., Trigenerative plant with organic Rankine cycle, *Termotehnica*, 2011 supliment II, ISSN 1222-4057

Books

[2] Rant, Z., Exergie, ein neues wort fur “Technishe Arbeitsfakiqkeit”, Forshung Ing. Wessen, nr. 1,1956;

[3] Bejan, A., Advanced engineering thermodynamics, John Wiley & Sons, 1988;

[4] Bejan, A., Entropy generation through heat and fluid flow, John Wiley & Sons, 1994;

[5] Bejan., A., Tsatsaronis, G., Moran, M., Thermal Design & Optimization, John Wiley & Sons, 1996;

[6] Szargut J., Exergy analysis of thermal, chemical and metallurgical process, Hemisphere Publishing Corporation, 1998;

Conference or symposium proceedings

[7] Dragan, M., Uzuneanu, K., Panait, T., Coman, G. Economic analysis of a combined heat and power plant with steam turbine. *Recent Advances in Fluid Mechanics and Heat & Mass Transfer – 9th IASME/WSEAS International Conference on Heat transfer, Thermal Engineering and Environment (HTE ’11),* Florence, Italy, Aug. 23-25, 2011, ISBN 978-1-61804-026-8, pp. 263 – 266.

[8] Dragan, M., Uzuneanu, K., Panait, T., Coman, G. The exergetic evaluation for the steam boiler. *Recent Advances in Fluid Mechanics and Heat & Mass Transfer – 9th IASME/WSEAS International Conference on Heat transfer, Thermal Engineering and Environment (HTE ’11)*, Florence, Italy, Aug. 23-25, 2011, ISBN 978-1-61804-026-8, pp. 267 – 270.

[9] Uzuneanu, K.**,** Panait, T., Dragan, M. Thermoeconomical Performance Criteria in Using Biofuels for Internal Combustion Engines - *Advanced in Energy Planning, Environmental Education and Renewable Energy Sources, 2010,* Published by WSEAS Press, ISBN 978-960-474-187-8, ISSN 1790-5095, pp. 81-86;

[10] Panait, T., Uzuneanu, K., Dragan, M. Reducing greenhouse gases emissions by using biomass in co-generation energetic plants- *Advanced in Energy Planning, Environmental Education and Renewable Energy Sources, 2010,* Published by WSEAS Press, ISBN 978-960-474-187-8, ISSN 1790-5095, pp. 87-90;

[11] Coman, G., Uzuneanu, K., Panait, T., Dragan, M. Finite difference analysis of ice formation outside a cylindrical wall. *Recent Advances in Fluid Mechanics and Heat & Mass Transfer – 9th IASME/WSEAS International Conference on Heat transfer, Thermal Engineering and Environment (HTE ’11),* Florence, Italy, Aug. 23-25, 2011, ISBN 978-1-61804-026-8, pp. 271 – 276;

[12] Coman, G., Uzuneanu, K**.**, Panait, T., Dragan, M. Use of the finite element method in modelling the heat transfer inside an artificial skating rink. *Recent Advances in Fluid Mechanics and Heat & Mass Transfer – 9th IASME/WSEAS International Conference on Heat transfer, Thermal Engineering and Environment (HTE ’11),* Florence, Italy, Aug. 23-25, 2011, ISBN 978-1-61804-026-8, pp. 277–281;

Rezumat*:* Deoarece unul dintre scopurile fundamentale ale termodinamicii tehnice este minimizarea generării de entropie prin înbunătățiri aduse proiectării termodinamice, lucrarea analizeaza procesele de comprimare si destingere.
Prin analiza ireversibilitătii proceselor de comprimare si destindere se va identifica efectul, cauza si masurile ce se pot lua pentru a se limita generarea de entropie si implicit distrugerea de exergie.
Cuvinte cheie: entropie,comprimare,destindere