ISOTHERMAL GAS COMPRESSION AND EXPANSION PROCESSES BY CONTROLLING ACTUATORS

Arpad Török[1],

[1] Sesam Technology SRL
Berceni, Romania

Michel Feidt[2]

[2] LEMTA, ENSEM, Université de Lorraine,
Vandœuvre-le-Nancy, Cedex, France

Presenter: Oana Laza[1]

1. INTRODUCTION

A revolutionary device for the compression/expansion of gases and vapors, realised on the basis of a new way of approaching energy problems in current thermodynamic installations, emphasizing the determining role of treating the exergetic aspects:

- the efficiency of real processes is limited by finite rate constraints
- an increase in the internal entropy of a system reduces the available exergy.
- **the exergy destroyed is proportional to the total rate of entropy generation**
  (Gouy-Stodola theorem)
- If engineering systems and their components are to function so that exergy destruction is minimized, their design must begin with minimizing entropy generation.

2. QUASI-ISOTHERMAL COMPRESSORS

In **the state of the art**, acceptable performances have been obtained in a fairly limited series of applications, with “near” isothermal devices, having as priority objective of the design, to find effective methods to reduce the polytropic index of the processes:

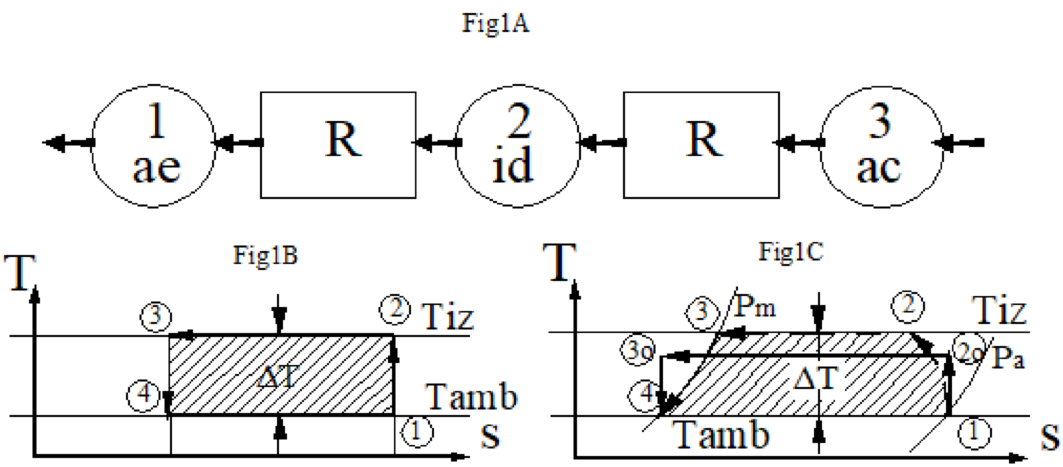
- the increase in heat transfer surfaces by introducing additional solid components into the device structure (Heidari et al, 2014, US 2002, IT 2005)
- the introduction, during processing, of certain lubricants, or liquid drops in suspension, or sprayed in intermittent jets (Coney et al, 2002, US 2011, 2013)
- the introduction of aqueous foam (Patil, 2019)
- the introduction of metal inserts in the case of liquid piston devices (US 2009)
- the use of special enclosure configurations (Saadat and Li, 2015)
- recovery of exhausted thermal energy (US 2007)
- mechanical control of piston speed (RO 2013 a, b)
- in the liquid piston, control of the flow rate of the working fluid, (Shirazi et al, 2013)
- introduction of metal inserts in the case of liquid piston devices (Caleb et al, 2009; Rice, 2017; Saadat et al, 2012).

3. THE ENDOREVERSIBLE ISOTHERMALIZER

- The heat transmitted to the gas by the piston can be only evacuated in the presence of a temperature difference ***ΔT*** between the gas and its surroundings. Unlike the other types of irreversibilities, this one cannot be avoideded (Rubin).
- This temperature difference *ΔT* can remain unchanged, and the process can become **isothermal**, if at each instant of the transformation, the gas transfers to its medium a quantity of heat equal to that transfered by the change in volume.
- The choice of the working temperature T_{iz} of the gas (and, implicitly, of the temperature difference *ΔT* relative to its ambient temperature T_{amb}) at which we want the isothermal transformation to take place is a compromise between the quantity of energy consumed in addition to the ideal compression (at *ΔT= 0,* energy efficiency $\eta=1$) and the duration of a cycle (which dictates the power consumed).
- The transformation undergone by the gas is isothermal ($T_{iz}=ct$), if the instantaneous power *Wi(t)* of the piston is permanently equal to the instantaneous heat *Qi(t)* transferred to the medium. This requires a change in the speed of the piston (isothermal trajectory). This piston speed is called **isothermal speed.**

We will call **ISOTHERMALIZER** (**isocompressor/densifier** in the case of compression and **isodetenter/rarefier** in the case of expansion), the device with cyclical operation, which is composed of one or more closed enclosures, with monotonically variable volume, containing gas at a monotonically varying pressure, whose temperature is constant for most of the duration of a cycle.

The **energy efficiency** of this transformation can be preset, simultaneously with the **isothermal temperature** : $\boldsymbol{\eta = W_{ideal} / W_{real}}$, where W_{ideal} is the work consumed for the ideal compression of the working gas (at T_{amb}). For exergetic reasons, the most energy efficient strategy is a three-step AIA (adiabatic-isothermal-adiabatic) process:



Energy efficiency η :

at $\Delta T = 0$, $\eta = W_{id} / W_{real} = T_{amb}/T_{amb} = 1$), $t \to \infty$

at $\Delta T \neq 0$, $\eta = W_{id} / W_{real} = T_{amb}/T_{iz} = T_{amb}/T_{amb} + \Delta T$

Izothermal condition:

for any t : $\boldsymbol{W(t) = Q(t)}$) , where:

$W(t) = P(t) \cdot dV = mRT_{iz} ln[P2(t)/P1]$

$Q(t) = C_{GT}(t)(T_{iz} - T_{amb})$, where $C_{GT}(t) = \Sigma h_i(t) A_i(t)$)

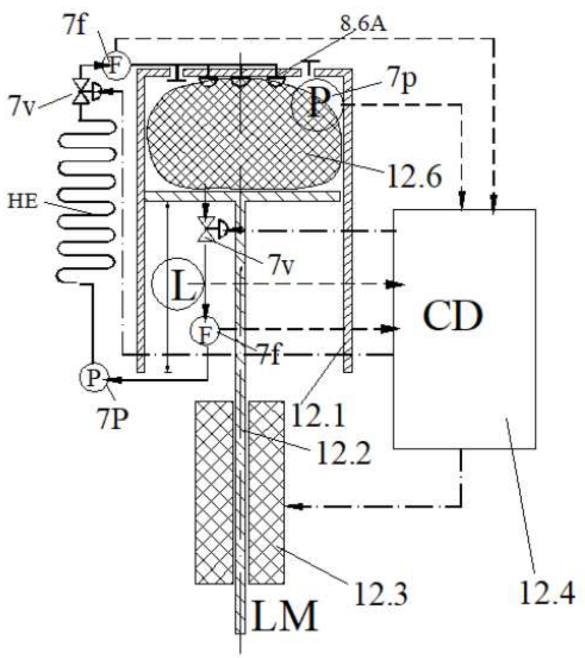
Figure 1: AIA stages. Fig.1A: 1=adiabatic expander 2=densifier, 3=adiabatic compressor, R=reservoirs
Fig.1B: T-s diagram of the evolution of the AIA. Fig.1C: T-s diagram of a polytropic-isothermal-isobaric evolution

Any novel or existing compressor (reciprocating, with solid/liquid piston, or rotary) can become an **ISOTHERMALIZER**,

- if it is equipped with:
  - ✓ an AIA system for the intake and discharge of the working gas
  - ✓ a system for adjusting the speed of moving parts
  - ✓ a thermal sponge to absorb/provide surplus/necessary thermal energy
  - ✓ an evacuation/supply system of this energy
- and if
  - ✓ this sub-assemblies is controlled, in real time, by a processor, programmed to achieve the constant preservation of the temperature difference *ΔT* between the gas and its surrounding environment

3.1. Isothermal speed

We equipped the device with AI and introduced a **closed-loop control device** into the system which, from information collected **real time** by a series of transducers determines the value by which the magnitude of the forces acting on the moving parts must change at that moment.



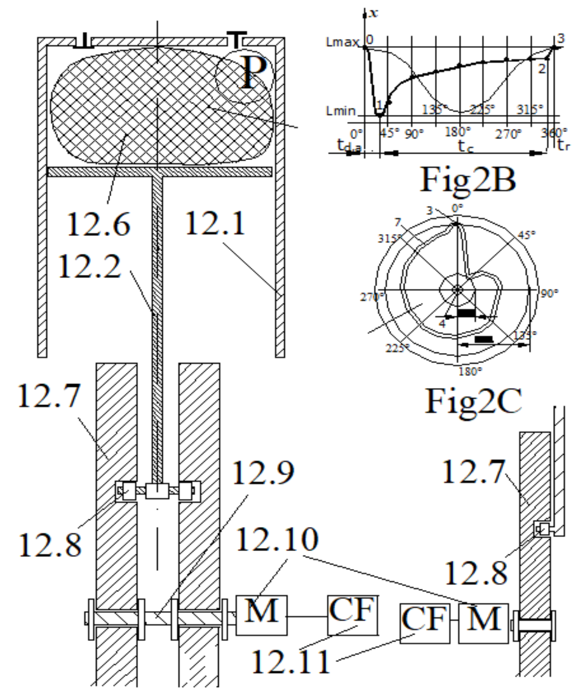


Figure 2: A: Isothermalizer with linear motor B: Isothermalizer driven by constant speed motor and profiled channel disc

3.2. The thermal sponge

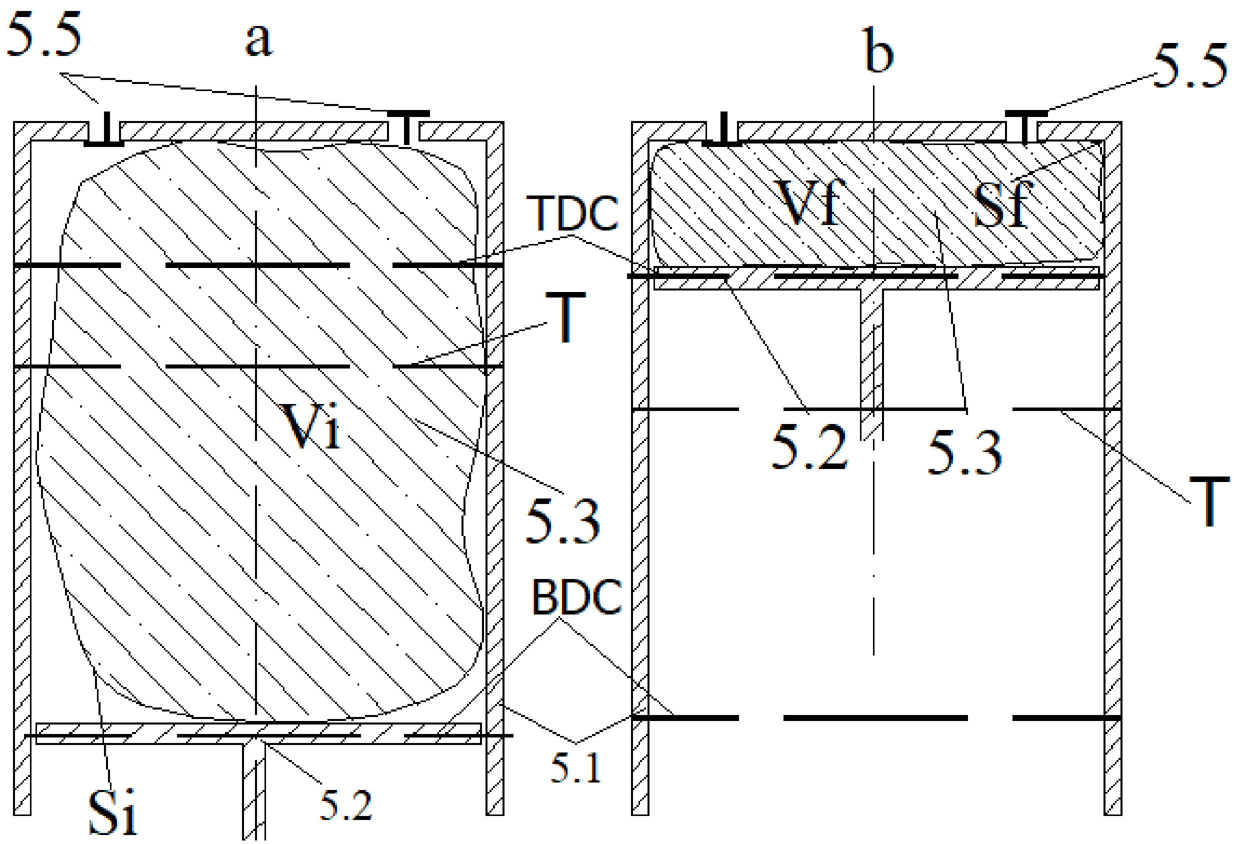
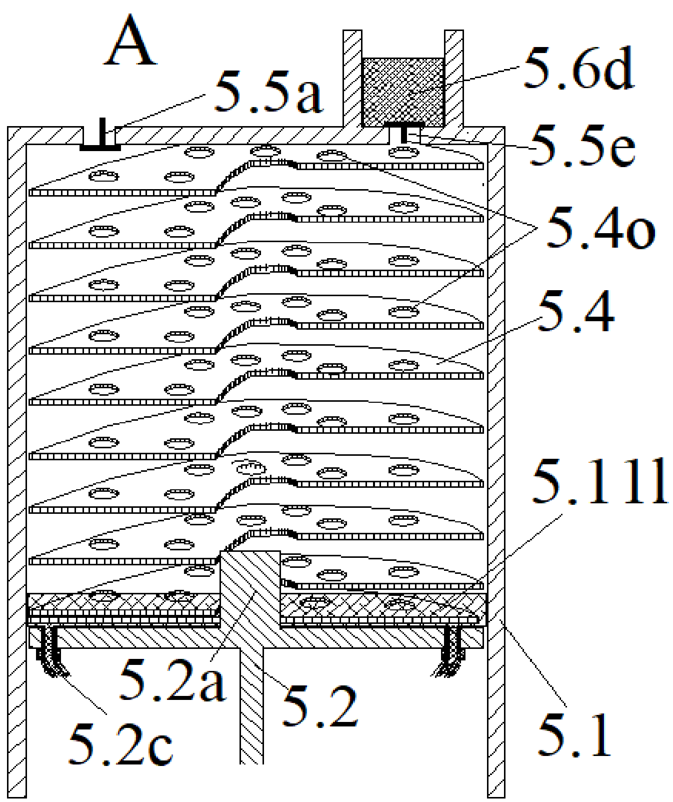


Figure 3. Deformable thermal sponge. 5.1: cylinder, 5.2: solid piston, 5.3: deformable sponge
a: with the piston at BDC, b: with the piston at TDC

The thermal sponge configurations



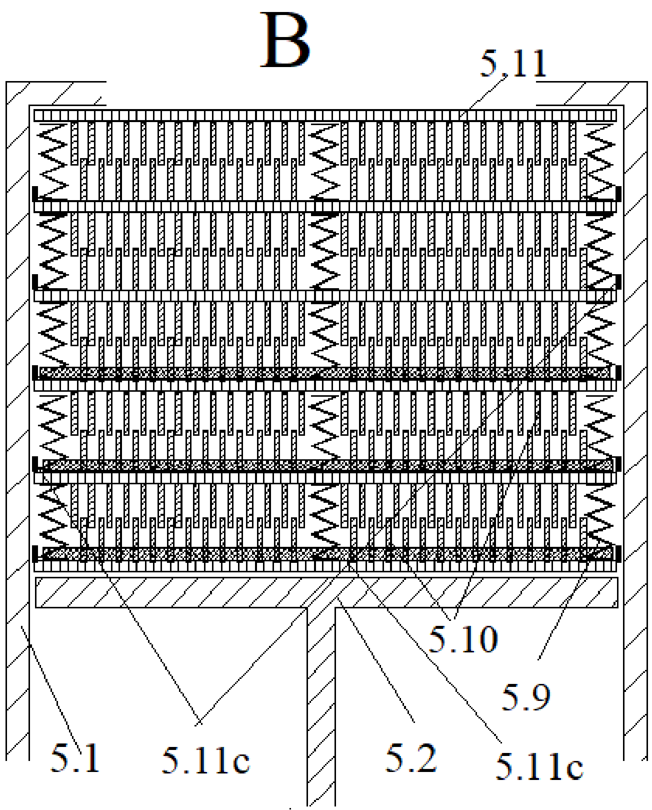


Fig.4A: helical spring 5.4 with rectangular section, Fig.4B: horizontal flat plates 5.11 with vertical fins 5.10

4. CONCLUSIONS

- Equipping devices designed for the compression and expansion of gases and vapors with real-time piston speed control systems allows any trajectory for *T(L)* (variation of temperature as a function of piston position) to be obtained, including the **isothermal trajectory**
- Devices equipped with a thermal sponge with a large absorption surface and efficient cooling systems can compress/expand, even at speeds comparable to those of state-of-the-art polytropic devices, large volumes of gas without exceeding a small temperature difference.
- These characteristics allow improving the performance of all processes in which the compression/expansion of gases, especially those working at high pressures, plays an important role and opens the prospect of creating innovative devices and installations, with a particular impact on the decarbonation of the environment

… WITH COUNTLESS POTENTIAL PRACTICAL APPLICATIONS:

- ❑ transport and storage facilities for all types of gas
- ❑ compression of gases at high pressures, in one stage, without heat exchangers
- ❑ simplifying gas liquefaction installations of any kind, by reducing or eliminating heat exchangers
- ❑ making gas-gas and gas-liquid heat exchangers with isothermal gas precompression
- ❑ CAES storage facilities, in one step
- ❑ thermal energy storage facilities, with the sequential change of the storage temperature
- ❑ thermal engines with external combustion, with small temperature differences between the two sources
- ❑ Ocean thermal energy conversion (OTEC) capture facilities
- ❑ waste and renewable energy capture facilities from low temperature sources
- ❑ high COP compressed gas heat pumps with Carnot/Ericson/Stirling cycle
- ❑ compressed gas heat pumps, with variable COP, modified with actuators
- ❑ heat pumps with isothermal vapor compression, with Ericsson cycle
- ❑ Carnot batteries, with high power density
- ❑ thermal engines with internal combustion and isothermal precompression, for changing the exhaust gas parameters of pressure and temperature
- ❑ thermal engines with internal combustion of hydrogen, without Nox exhaust