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JANUSZ BADUR[1]

Energy – conversion, conservation and management

The Szewalski Institute of Fluid Flow Machinery of the Polish Academy of Sciences, Energy Conversion Department, Fiszera 14, 80-231 Gdańsk, Poland

Abstract

Energy is an abstract notion that helps to understand the nature and contributes to the creation of the civilization. The energy notion has a huge meaning not only due to practical reason – it is essential for economy and philosophy too. It turns out that in Hellenic philosophy, and especially in its fundamental part, i.e., metaphysics, there is no place for the concepts and methods of reasoning developed by physics and chemistry. Philosophy assumes that most of the physical and chemical concepts are not known in nature *in spe* – these are employed by science only as a kind of mental keys (*qualitative occultea*) for the description and understanding of the universe. The concept of *energy* is only one example of a notion accepted both by the philosophers (in its metaphysical sense) and physicians (in its descriptive role).

Keywords: Internal, kinetic and potential energy; Energy fluxes; Energy conservation; Energy conversion

1 Hellenistic foundations of energy concept

The Arystotelian physics considers the energy as a fundamental feature of the nature which serves as a basis for other – the already known and yet not known features of the nature. Without energy in the metaphysics there is no creation of matter, no creation of weightless fields, no any formation

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[1] E-mail address: jb@imp.gda.pl

and decay of all of the driving potentials of nature. In the Aristotelian metaphysics, the energy has only two forms of realization. One of them is a basic, pure and inaccessible potential of nature, that may create a form of active and visible world during the act of creation. The second form of energy of motion is permanently involved in a process of creation and annihilation of beings. It 'pours' from the unavailable source to the real world and *vice versa* – our reality 'dies', thus becoming a pure potency of nature again.

The basic method of the physical world creation from the pure potential is an 'energy action' (as defined mathematically by Maupertuis, 1744), which takes place on a quantized way, thus creating a quantized real beings. As far as the metaphysical knowledge can be assimilated by an illumination only, this part of philosophy is no longer being developed Heller [6]. However in an implicit manner, by the creation of the paradigms of thinking, metaphysics is still present in the process of human cognition. For example, the thesis of quantized action, has its hidden implications in the modern *quantum thermomechanics*, and the thesis of the existence of '*eternal light*' is the prototype of the '*dark energy*' concept in cosmology. Metaphysical energy partition into potential and action is an analogue of the potential energy (gravitational field) and the kinetic energy of body motion. In summary, the Aristotelian metaphysics and his successors brought the fundamental paradigms of thought to the energy science.

One is an inherent relationship between the energy and the peripatetic motion, because the active energy is an integral measure of the amount of motion. The opposite to this peripatetic motion is immobility of the nature's source which can be measured by the perfect potential. The paradigm of the peripatetic motion is still present in our reasoning that concerns the principles of the energy conversion and the transformation of its forms. The peripatetic motion is a *quantum motion*, that constitutes every other motion, thus being the basis of all chemical processes, nuclear physics, mechanics and thermodynamics. It means that the energy as an integral measure of peripatetic motion is equal in its elementary quality, therefore energies of mechanical, heat, electrical and magnetic motions can be added without the necessity of using of any energy conversion factors (equivalents). In other words, in the Aristotlelian metaphysics, all known energy equivalents as heat-mechanical (Rumfold, Carnot, Joule), electro-chemical (Faraday), electro-mechanical (Thomson), mechanical-heat (Clausius) are equal one. In 1850, this concept of homogenous energy was adopted from the Greek philosophy by Rankine [1], who assumed quantized energy transfer by the 'vortex atom'.

2 Disputes over *vis viva* and *impetus*

In the Middle Ages the metaphysics and natural philosophy of Aristotle was discarded and the concept of peripatetic motion was limited only to the so-called local mechanical motion (Bourdin, 1211) (for historical data see: [7]). The laws governing the mechanical motion were still unknown since the Aristotelian dynamics appeared to be wrong. There was a need to define a '*topological charge*' which ensures the continuation of arrows motion during the flight, and which would define the amount of available motion. Candidates were: mv the product of mass, m, and velocity, v, (momentum) and other product mv^2 called by philosophers *vis viva* (Leibnitz, 1667). But even after Newton's 1678 discovery, who found that the real cause of the mechanical motion is *vis impressa* (geometric version) and that the momentum of the universe is constant, there were disputes over the primary force that governs the mechanical motion, i.e., *vis viva* or *vis impressa*.

Such disputes were continued also after the works of Wallis (1699) and Euler (1729) which gave the analytical form of Newton's *lex secunda*: $m\vec{a} = \vec{f}$, the net force is equlited the product of the mass times the acceleration, $\vec{a}$. The historical studies by Duhem, and then also by Truesdell [5], showed however, that when the peripatetic motion other than mechanical motion was considered then natural philosophers have used the more general notion of *vis viva*. This dichotomy of thinking had continued through the eighteenth century. For example Johan Bernoulli (1741), when defining the law of motion of the liquid in the pipes, employed the momentum balance (balance *vis impressa*), and apparently Daniel Bernoulli (1739) used as a law of motion the integral form of *vis viva* balance.

3 Kinetic energy

The Rankine's concept of internal energy can be treated to some extent as an analytical representation of Aristotle's division of entelechy of motion into the potential and active parts. It is also mentioned by Rankine (1855) during development of the 'kinetic energy' concept: $\frac{1}{2}\, m\vec{v}{\cdot}\vec{v}$. He treated all perceptible physical world of matter as a manifestation of an active motion. This motion can be divided into balanced internal motion, measured quantitatively by the internal energy, and an external energy of motion, which is only a qualitative component of *vis viva*, called the 'kinetic energy'. Because both the internal and kinetic energies are of the same nature, these can be calculated using the same units, without employing Joule's equivalent of energy. Rankine was in some opposition to Joule, whose goal was to find the equivalent as a ratio of internal energy to the kinetic energy ($J_{Joule} = \mathcal{U}/\Psi$), where $\mathcal{U}$ is the total internal energy, and Ψ is the total kinetic energy. Joule's approach was also innovative, but only in relation to the concept of Sadi Carnot who was preferring the equivalent of work in the form $J_{Carnot} = \mathcal{W}_{cycle}/\mathcal{Q}_{cycle}$, where $\mathcal{W}_{cycle}$ is the work done by a cycle and $\mathcal{Q}_{cycle}$ is the heat converted in the same cycle.

4 Potential energy

The concept of the energy potential, Φ, was introduced, firstly by Boscovich in his *Theoria philosophiae naturalis*, and next by Laplace in 1797 for the description of the gravitational force (*vis viva moltara* later *vis latente*) acting between two massive bodies (action at distance). Laplace assumed that each of the massive bodies coming from the nature's source of potential posses the spatial memory of this source, which is described by involved energy of the source Φ. In other words, the Laplace's concept described the action of the anticipated gravitational field by the potential, later called the potential energy.

This concept had a huge advantage over Newton's gravity model – in this concept there is no need for adjustments in the form of additional postulate of the existence of *eternal light*. Recall that the Newton's model had a serious drawback. His concept did not describe the permanence of the firmament (*Stellae Fixae*), and to explain why the stars do not fall one another, Newton postulated an additional unknown, i.e., the pressure of light – *eternal light*, which repelled the stars from each other. Today the role of the eternal light in cosmology meets the *dark energy* notion also postulated *ex nihilo* [6]. Under earthly conditions the Laplace potential is described accurately enough by the distance of the body from the Earth surface enlarged by Earth's radius (position vector). Now extending the Gibbs-Rankine's concept of state parameters also for the potential energy Φ, it can be concluded that the position vector, $\vec{x}$, plays a role of the primary state parameter, and the gravitational acceleration, $\vec{b}$, is a dual state parameter: $\vec{b} = \partial\Phi/\partial\vec{x}$.

5 Energy of radiation

There exists also an additional, internal energy – energy of radiation – which is not associated with the substance of the working medium and which is localized in space. In 1865, Maxwell proposed that this nonsubstantial energy of electromagnetic field, e_{em} , can be expressed by the primary state parameters as electric field, $\vec{E}$, and magnetic field $\vec{H}$. Maxwell identified also the dual state parameters of radiation energy, i.e., the electric displacement vector, $\vec{D} = \partial e_{em}/\partial \vec{E}$, and the magnetic displacement vector $\vec{B} = \partial e_{em}/\partial \vec{H}$ [2]. This concept allows later to formulate the energetically consistent theory of radiative heat transfer by Planck in 1905.

6 Internal energy

It can be noticed that all of these proposals and hypotheses refer to the perfect phenomena of nature, which are not yet affected by human activity. The Industrial Revolution of eighteenth century, however, resulted in application of a tremendous amount of machineries and heat engines. There was a reasonable demand for the governing laws of practical meaning – it was especially important from the economical point of view. The machines operate periodically, thus the mechanical motion in the single cycle is a self compensating quantity. Therefore in the process of analyzing the operating principles, the main role played the technical concepts such as *heating* and *working*, which allowed to define usefulness of the thermal engine in every single cycle. The working and heating processes, if continue for some time, may be defined by an abstract, integral in time quantities, i.e., *work* and *heat*.

By the fact that it was possible to measure the effects of both processes, which were accumulated in the form of work or heat 'storages' located within the working medium, a new complex and abstract concept could be introduced – the concept of energy storage or energy stored in the working medium. Initially the work storage (work supply) and heat storage (heat supply) were treated independently. Depending on whether the law of conservation of energy was formulated in units of work (Clausius, 1850) or in units of heat (Thomson, 1854), the substantial work or heat storages could be specified. Only Rankine (1850), writing the law of conservation of energy in an analytical manner postulated by Mayer and Joule's, concluded that there is only one universal energy storage – the *internal energy*, which has the single internal medium that is common to all forms of energy transfer. Rankine also stated that all energy equivalents are thus redundant. This was, in relation to the statements of Clausius and Thomson, an extremely radical step which breaks the fundamental paradigms on separateness of energy forms.

In terms of Clausius, the substance subjected to the process of working can accumulate and store work without any losses and then, after moving the continuum (working body) in another place, can release it at any time – but only in the same mechanical form. Then, under the irreversible operation the working process can be transformed into the heating process in an amount determined by the mechanical equivalent of heat, $A_{Clausius}$. It should be underlined, that the concept of accumulation of work in the medium in the form of 'work supply' had some origins in consideration on simple machines where mechanical energy is transformed in the same type of energy. This led to the law of energy balance that was limited only to the mechanical phenomena (Lazar Carnot, 1803, integral in time and space). Quite early appeared the mechanical case of internal energy per unit mass of the substance. It was Green's internal energy (1839) for three-dimensional elastic deformation of a solid body and Petit's internal energy (1818) for a three-dimensional rapid compression of gas. Sir Edmund Whittaker (1910) noted, however, that the Green's internal energy not exactly refers to solid. It was Kirchhoff (1850) who used it first to derive the simplified equations of motion of a thin plate.

In terms of Thomson, the internal energy was expressed in units of heat and was defined by him as a 'heat supply' that is ready to be transferred outside without any losses. Thomson's version of the internal energy conversion principle assumes that the working medium posses the ability of accumulation of the *heating process* effects only as a *heat.* The body which is warmed in a one place, can transfer the energy outside in another place and time, but only during the *heating process.* Under an irreversible processes, the heating may evolve into working, which can be calculated using the thermal equivalent of work, J_{Joule}. Both Clausius and Thomson emphasized the ideality of internal energy storage, which means that nothing is lost from the 'work supply' (Clausius) or 'heat supply' (Thomson). The medium at first adopts and later gives back the same amount of work or heat.

The current definition of internal energy was finally given in 1850 by Rankine. His revealing hypothesis on *the internal energy conversion* assumes that the matter of the working medium does not store neither *heat* nor *work*. The working medium during heating process does not increase their heat supply but increases its internal energy and similarly the working medium during working process does not increase its work supply but also increases its internal energy. Thus the conversion of energy of mechanical motion into the thermal motion posses an intermediate steps in the form of the internal energy changes. This transformation occurs during charging or emptying of internal 'storage'. In other words, the thermal energy transferred to the medium in the heating process leads to the increase of the medium's internal energy and the internal energy can 'leave' the medium, for example converting itself into work (working process).

Such internal transformation is possible due to the motion of atoms, electrons, molecules, etc. In the working medium there is only one universal type of reversible energy storage. Rankine's model of internal energy conversion that bases on the anticipated concept of 'vortex atom', does not differ much from the contemporary models of the atom, the nucleus and electrons. The external energy fluxes related to heating and working processes, inside the Rankine's vortex atom transform into a hidden Aristotelian active energy, or hidden generalized *vis viva*: $m\vec{v}\cdot\vec{v}+\vec{w}\cdot\overset{\leftrightarrow}{I}\vec{w}$, where $\overset{\leftrightarrow}{I}$ is the inertia tensor and $\vec{w}$ is the rotational velocity, which consists of translational and rotational *vis viva*. The conversion of energy which is received by an external observer as a replacement of heating by working process, also takes place inside the Rankine's vortex atom in a reversible manner as a change of $\vec{w}\cdot\overset{\leftrightarrow}{I}\vec{w}$ into $\vec{v}\cdot\vec{v}$. In the frame of Rankine's vortex atom (1851) temperature and entropy (called by Rankine *a thermodynamic function*) have a clear geometric presentation. They are introduced as parameters of state – that is, the parameters associated with reversible energy storage. It is fundamentally different concept than one presented by Clausius (1865), who needed fourteen years to came with the concept of entropy embedded in the chaotic motion of millions of moving gas molecules.

The Rankine internal energy concept was creatively extended by Gibbs (1876), who was probably one researcher, except Truesdell, able to properly interpret the work of Rankine. Gibbs perceived that Rankine's model of vortex atom is so comprehensive that it can also describe the chemical, magnetic and electric energy storages. Therefore, instead of many different storages, Gibbs introduced a universal internal energy, which is responsible for the implicit transformation of energy. The Rankine internal energy paradigm, supplemented further by Gibbs, is still in use in the thermodynamics of continuum, and perhaps also in the whole physics and chemistry. Idea of internal energy describes the mechanism of reversible accumulation of energy, which is transferred to the mass unit of the medium during different processes such like: mechanical working, heating, electrical, magnetic and chemical working, etc. Internal energy is a primary quantity which cannot be measured directly.

7 Thermodynamical parameters of state

Together with the concept of the internal energy a new notions have been introduced by Rankine – the thermodynamical parameters of state, which allow to estimate the change of internal energy. Two parameters were attributed to the every form on energy – primary one, which is intensive and a secondary one, which is dual, extensive. The first parameter was named *mataforic function* and the second was called a *methamorphic function* (Rankine, 1855). The first examples of the parameters of state for gas were the specific volume and the specific entropy (intensive parameters) and complementary to them thermodynamic pressure and temperature (extensive parameters). There are more parameters when the solid body is considered, namely tensor of deformation density, tensor of specific entropy and complementary to them tensor of stresses (pressure) and tensor of temperature.

The parameters of state in the Rankine proposal were a practical way for calculation the amount and the change of the internal energy. The primary, intensive parameters of state, do not reflect individualism of the internal motion, they are anthropocentric, convenient for measurements averages over the internal motion. Unfortunately, the internal energy conversion so clearly imagined by 'vortex atom', when analyzed in terms of parameters of the state, is no longer a simple representation. It hard to imagine graphically an exemplary conversion as for the case when the internal energy remains constant but the specific volume decreases at the expense of the specific entropy increase. The internal energy concept expressed by primary parameters of state was finally formulated by Gibbs (1873), who defined the relationship between primary and dual parameters of state:

$$\text{dual parameter of state} = \frac{\partial(\text{specific internal energy})}{\partial(\text{primary parameter of state})}\,. \tag{1}$$

This equation is one of the most fortunate in the thermodynamics foundations. It allows to relate the set of equations describing the arbitrary process with the law of energy conservation. The equations which describe the physical processes, such as heat conduction in the solid body, may be erroneously formulated in the sense that they can lead to the violation of the law of energy conservation. Therefore, in order to transform the describing equations such as, for example, the Schrödinger equation into the energetic relationship, it is necessary to know Gibbs' constitutive relation, Eq. (1), and the well-defined partial energy fluxes for working and heating processes of all kind.

Gibbs realized that for the internal energy changes occurring due to changes of the primary parameters of state, it is important to determine the total internal changes expressed by changes of both primary and dual parameters of state:

$$\begin{aligned} &d\,(\text{specific internal energy}) = \\ &\quad = \sum \begin{pmatrix} \text{dual} \\ \text{parameter of state} \end{pmatrix} d \begin{pmatrix} \text{primary} \\ \text{parameter of state} \end{pmatrix} , \end{aligned} \tag{2}$$

which have exemplary form:
for fluids

$$d\varepsilon = p\ dv + \theta\ d\eta + \mu\ dc + \dots\ , \tag{3}$$

for solids

$$d\varepsilon = p_{ij}\ dv_{ij} + \theta_{ij}\ d\eta_{ij} + \mu_{ij} dc_{ij} + \dots\ , \tag{4}$$

where ε is the specyfic internal energy, p, θ and μ are the pressure, temperature, chemical potential, and v, η, c are the specific volume, specyfic entropy and specific concentration, respectively. Supscripts $i, j = x, y, z$ denotes cartesian coordinates.
Here increment d means the substantial differentiation in time (d/dt). For the solid bodies, which accumulate not only volumetric, but also shape changes, exist tensors of specific deformations, specific entropy, specific concentration etc.

8 Mathematical denotation of fundamental concepts

To make learning about energy effective it is necessary to assign the mathematical objects to the verbal concepts. Since in literature there exist dozens of different mathematical signs for the same quantities it is reasonable to employ the system of denotations as proposed in the papers of pioneers, mostly Rankine, Gibbs, Duhem, Natanson (Kestin 1980). The method of description bases here on the foundations of rational thermodynamics by Truesdell (1980) and Kestin (1980).

Let us mark the finite volume by the sign $d\mathcal{V}$, and the volume of thermodynamic system $\mathcal{B}$ by letter $\mathcal{V}$. The system $\mathcal{B}$ interacts with the external environment by the processes acting at the system boundary $\partial\mathcal{V}$. The internal, kinetic and potential energy can be denoted by $\mathcal{U}$, $\mathcal{K}$, Φ, respectively, and the energy of radiation by $\mathcal{E}_{em}$. All these quantities are expressed in the energy unit – joule's . These integral for the system amounts of the energy reflect in a good manner the anthropocentric character of our knowledge and they are commonly employed in the science and technique. Beside the integral quantities there are some quantities related to the unit of mass, as:

$$\text{internal energy } \ \mathcal{U} = \iiint_{\mathcal{V}} \rho\ \varepsilon\ d\mathcal{V} = \iiint_{\mathcal{V}_0} \rho_0\ \varepsilon\ d\mathcal{V}\ , \tag{5}$$

$$\text{kinetic energy } \ \mathcal{K} = \iiint_{\mathcal{V}} \frac{1}{2}\ \rho\vec{v}\cdot\vec{v}\ d\mathcal{V} = \iiint_{\mathcal{V}_0} \frac{1}{2}\ \rho_0\vec{v}\cdot\vec{v}\ d\mathcal{V}\ , \tag{6}$$

$$\text{potential energy } \ \Phi = \iiint_{\mathcal{V}} \rho\phi\ d\mathcal{V} = \iiint_{\mathcal{V}_0} \rho_0\phi\ d\mathcal{V}\ . \tag{7}$$

Two volumes of system can be distinguished – the referential volume $\mathcal{V}_0$, nondeformed, using in the Lagrangean description, and the actual volume $\mathcal{V}$ related to the Eulerian description.

Let's denote by ρ_0 and ρ the mass density in its initial state and actual state respectively. Following Gibbs the specific internal energy [J/kg] related to the unit mass can be denoted by letter ε. The quantities $\rho\varepsilon$ and $\rho_0\,\varepsilon$ are volumetric energy densities related to actual and initial volumes, respectively. Fourth kind of energy that undergoes balancing is an energy of radiation:

$$\mathcal{E}_{em} = \iiint_{\infty} e_{em}\ d\mathcal{V}\ , \tag{8}$$

where the unit [J/m^3] is a volumetric density of energy of electromagnetic field postulated by Maxwell (1874). It means, that the field quantity cannot be related to the mass of substance, and only to the volume where the radiation acting. Let us, according to Rankine, assume that the energy fluxes are additive. It allows to formulate the total energy flux, $\mathcal{F}_{energy}$ [J per second], as the sum of particular processes

$$\mathcal{F}_{energy} = \mathcal{F}_{work} + \mathcal{F}_{heat} + \mathcal{F}_{chem} + \mathcal{F}_{elec} + \mathcal{F}_{mag} + \dots\ , \tag{9}$$

where respectively appear: working, heating, chemical, electric and magnetic energy fluxes. This mathematical set can be treated as universal one – there is a place for new, yet unknown processes. There is a lack of radiative flux, described by the Poynting vector (1899), because it is directly related to the system substantial boundary. The substantial boundary $\partial\mathcal{V}$ is oriented outside by the normal unit vector $\vec{n}$, that allows to write the energy flux as a normal component of the total energy vector:

$$\mathcal{F}_{energy} = \iint_{\partial\mathcal{V}} (\vec{\mathcal{F}}_{work} + \vec{\mathcal{F}}_{heat} + \vec{\mathcal{F}}_{chem} + \vec{\mathcal{F}}_{elec} + \vec{\mathcal{F}}_{mag} + \dots) \cdot \vec{n}\, dA\,, \quad (10)$$

where dA denotes a surface where the fluxes are supposed. Two first energy fluxes are very well known in literature: $\vec{\mathcal{F}}_{work}$ is a mechanical energy flux of Umov (1874) and Volterra (1899), and $\vec{\mathcal{F}}_{heat}$ is a heat energy flux of Rankine (1851) and Stokes (1851).

The essence of the proper definition of the various fluxes is to find the proper relationship of the energy flux with the fluxes of momentum, angular momentum, mass, entropy, electricity, etc. If the internal energy ε is expressed by the primary parameters of the state and there are no spatial and time gradients of the parameters of state, then, as shown by Truesdell and Kestin, fluxes of the mechanical energy and heat can be expressed by a relatively simple combination of the momentum flux tensor, $\overset{\leftrightarrow}{t}$, and entropy flux vector, $\vec{h}$:

$$\vec{\mathcal{F}}_{work} = \overset{\leftrightarrow}{t}\ \vec{v}, \quad \vec{\mathcal{F}}_{heat} = \theta\vec{h}\,, \quad (11)$$

where $\vec{v}$ is the velocity vector of the substance and θ is the absolute temperature. In the case of the field energy there exists the Pointing radiation energy flux defined as $\vec{\mathcal{F}}_{em} = \vec{E} \times \vec{H}$, where $\vec{E}$ and $\vec{H}$ are the electric and magnetic field, respectively.

The universal law of energy conservation can be now anticipated. This universal law states that the change of the system of the energy storage occur at the expense of processes (fluxes), or mathematically

$$\frac{d}{dt}(\mathcal{U} + \mathcal{K} + \Phi + \mathcal{E}_{\mathrm{em}}) = \iint_{\partial\mathcal{V}} \vec{\mathcal{F}}_{energy} \cdot \vec{n}\, dA + \iint_{\infty} \vec{\mathcal{F}}_{em} \cdot \vec{n}\, dA + \mathcal{S}_e\,. \quad (12)$$

Here, the energy source $\mathcal{S}_e$ is a measure of nonconservation of the energy. For the phenomenon occurring between time t_{in} and t_{out} (time scale associated with human activity) this energy balance equation can be integrated.

Due to the reversibility of the total energy storage, the time integral of

LHS in Eq. (12) depends only on the initial and final state of the storage. As far as the occurring processes are summed accurately the Eq. (12) finally transforms into

$$(\mathcal{U}+\mathcal{K}+\Phi+\mathcal{E}_{em})\Big|_{t_{in}}^{t_{out}} = \int_{t_{in}}^{t_{out}} \left(\mathcal{F}_{energy}+\mathcal{F}_{em}\right) d\tau \;, \tag{13}$$

where $d\tau$ denotes the time increment. It is a formulation known as an integral in time and integral in space form of presentation of energy conservation law.

Special integral form can be obtained for the phenomenon occurring periodically. In this case the summary energy changes in a single cycle are equal zero, and the balance can be simplified to the *cyclic integrals of fluxes*, which cancel each other. If considered phenomenon consists of heating and working processes, then their integrals are called the heat of the cycle and work done by a cycle, and Eq. (13) can be rewritten as

$$\mathcal{F}_{work}^{cycle}+\mathcal{F}_{heat}^{cycle}=0 \;, \tag{14}$$

which can be read as follows: After single, complete cycle of transformations the internal, kinetic and potential energy of working medium takes on its initial value, and the work done/received by a cycle is equal the heat released/received by a cycle:

$$\begin{aligned} \mathcal{F}_{work}^{cycle} &= \oint \Big(\textstyle\iint_{\partial V} \vec{\mathcal{F}}_{work}\cdot\vec{n}\; dA\Big) d\tau = \oint \Big(\textstyle\iint_{\partial V} \overset{\leftrightarrow}{t}\;\; \vec{v}\cdot\vec{n}\; dA\Big)\; d\tau \\ \mathcal{F}_{heat}^{cycle} &= \oint \Big(\textstyle\iint_{\partial V} \vec{\mathcal{F}}_{heat}\cdot\vec{n}\; dA\Big) d\tau = \oint \Big(\textstyle\iint_{\partial V} \theta\; \vec{h}\cdot\vec{n}\; dA \;\Big)\; d\tau \;. \end{aligned} \tag{15}$$

The law of total energy conservation – known as a First Law of Thermodynamics – should decide about the existence of internal energy source $\mathcal{S}_e$, that formally appears in balance (Eq.12).

9 The law of energy conservation

One of the most fascinating steps of civilization is related to the energy conservation law – its anticipation, development and rational explanation. Until today there is no any empirical evidence of the conservation of energy – nevertheless in the opinion of researchers it is the most unquestionable and inviolable law of nature. Its philosophical origins come from Greek's metaphysics who assumed that more general law of the conservation of peripatetic motion is valid in the nature. This law can be split then to many special laws of conservation, which cannot necessarily be a scalar as in the case of energy. Leonardo da Vinci (1499) disagreed with this concept. He compared the nature and the man himself to the great machine, and hence da Vinci can split the law of the conservation of peripatetic motion into two special laws: (a) there is no possibility of existence of the eternal engine in the nature (*perpetuum mobile* of the first kind); (b) there is no possibility of any mechanical perpetual motion in the nature (*perpetuum mobile* of the second kind).

This concept had enormous impact on the scientific investigations in the *nineteenth century.* It became the prototype for the *First and Second Principles of Thermodynamics.* Kuhn (1959) noticed that there were at least 12 researchers who contributed to the final formulation of the law of conservation of energy and its mathematical representation. In fact, more than 12 researchers should be considered [3]. For example, already Sadi Carnot in 1824 postulated the law Eq. (14) in the form: $2.7\ \mathcal{F}^{cycle}_{work} + \mathcal{F}^{cycle}_{heat} = 0$, which did not require a prior knowledge of the concept of 'internal energy'. On the other hand, Mayer (1842) and Joule (1847) formulated the law of indestructibility of energy and assumed that the system is not affected by any processes, i.e., $\mathcal{F}_{energy} = 0$, and the law of conservation of energy has a simple form that consists of three parts

$$\mathcal{U} + \mathcal{K} + \Phi = const\ . \tag{16}$$

In the case of a large systems such like the universe, this balance leads to $E_{Universe} = \mathcal{U} + \mathcal{K} + \Phi = const = n\ E_{Sun}$. It is formulated by Mayer (1851) in the form of: energy of the universe, $E_{universe}$, is constant and approximately equals the number of stars in the firmament, n, multiplied by the energy of the Sun, E_{Sun}.

The universal conversion law for all energy fluxes was verbally formulated by Grove (1841), and mathematically written by Helmholtz (1847). The principle of energy conversion stated that the substance has the ability to receive the energy by one process, is able to store it without any losses, and is able to release energy by another process. The final theory of energy conversion was developed by Rankine (1855) and now it is an inviolable foundation of the mathematical description of all the natural phenomena.

Today there is an agreement that the key hypothesis of energy conservation given by Mayer and Joule, saying that energy is indestructible, can be used even in the smallest subatomic scale. In practice, the source of energy in total energy balance, Eq. (12), must always be equal to zero, regardless the volume of the considered system:

$$\mathcal{S}_e = \iiint_{\mathcal{V}} \rho \; s_e \; d\mathcal{V} = 0 \; . \tag{17}$$

where s_e is the specific energy source like dark energy, the vacum energy, etc. It means that in the nature there are no any processes which can create a new amount of energy. Researchers are convinced that the energy is indestructible despite of the fact that energy is only a scalar, coarse and abstract invariant of processes occurring in nature.

10 Energy conversion

From the traditional point of view the conversion (or transformation) of energy is defined to be a process in which energy transform from forms provided by nature to forms that can be used by humans.

Over the centuries a wide spectrum of devices and systems has been developed for this purpose. Some of these energy converters are quite simple. The early windmills, for example, transformed the kinetic energy of wind into mechanical energy for pumping water and grinding grain. Other energy-conversion systems are decidedly more complex, particularly those that take raw energy from fossil fuels and nuclear fuels to generate electrical power. Systems of this kind require multiple steps or processes in which energy undergoes a whole cascade of transformations through various intermediate forms.

There are many examples of conversion processes that appear as routine phenomena in nature, such as the evaporation of water by solar energy or the storage of solar energy in fossil fuels. In the technology, conversion is more generally applied to operations of human origin in which the energy is made more usable; for instance, the burning of coal in power plants to convert chemical energy into electricity, the burning of gasoline in automobile engines to convert chemical energy into propulsive energy of a moving vehicle, or the burning of a propellant for ion rockets and plasma jets to provide thrust.

There are so many different kinds of energy that can transform from one form to another. There is energy from chemical reactions called chemical energy, energy from thermal processes called heat energy, and energy from charged particles called electrical energy. The process of fission (splitting atoms) and fusion (combining atoms) gives us another type of energy called nuclear energy. And finally, the energy of motion (kinetic energy) and the energy associated with position (potential energy) are collectively called mechanical energy.

From the mathematical point of view, modeling of energy conversion is somewhat difficult, and needs special tools. In central place is located the internal energy which is energy stored within a substance: for instance – the chemical energy is the energy stored through the bonds of chemical compounds. This energy stored in these chemical bonds can be released and transformed during any type of chemical reaction. Internal energy consists also recoverable mechanical energy which is the energy stored by any object that can stretch or compress.

Electrical internal energy is the energy stored and carried by charged particles as they move around a conductor. In time of electric current flowing, part of energy concerts into heat $\mathcal{F}_{elec} \rightarrow \mathcal{F}_{heat}$ which change the internal energy as well. Internal chemical energy can also be converted into electrical energy $\mathcal{F}_{chem} \rightarrow \mathcal{F}_{elec}$. For example, the chemical energy in a battery is converted into electrical energy. The electrical energy, which involves the motion of electrical charges or currents, can be used to power everyday devices like computers and flashlights.

Mechanical energy can also be transformed into electrical energy $\mathcal{F}_{work} \rightarrow \mathcal{F}_{elec}$. For example, a hydroelectric plant uses the mechanical energy of flowing water to generate electrical energy. Wind energy is another mechanical to electrical energy transformation. The mechanical energy of the wind is transformed into electrical energy which can be then transformed into other types of energy. a nearly-full matrix of possible conversions had been founded by Grove in 1841. Marie and Pierre Curie have added yet additional nuclear conversion.

11 Energy management

Energy management is a new notion that has a number of meanings, mainly is concerned with the one that relates to saving energy in businesses, public-sector and government organizations, as well as households. Firstly, it includes planning and operation of energy-related production and consumption units. Among many objectives three are most important:

– resource conservation,

– climate protection
– cost savings.

From economical point of view a definition of energy management, that includes the economic dimension is: “Energy management is the proactive, organized and systematic coordination of procurement, conversion, distribution and use of energy to meet the requirements, taking into account environmental and economic objectives” [8].

It is important to integrate the energy management in the organizational structure, so that the energy management can be implemented. Responsibilities and the interaction of the decision makers should be regularized. The delegation of functions and competencies extend from the top management to the executive worker. Furthermore, a comprehensive coordination can ensure the fulfilment of the tasks.

There is no resource conservation without the energy-saving. It means that, energy management is the process of monitoring, controlling, and conserving energy in a building or organization. Globally we need to save energy in order to:

- Reduce the damage that we’re doing to our planet – Earth. As a human race we would probably find things rather difficult without the Earth, so it makes good sense to try to make it last.
- Reduce our dependence on the fossil fuels that are becoming increasingly limited in supply.
- Reduce costs – this is becoming increasingly important as energy costs rise.
- Reduce green house emissions and the environmental damage that they cause – as well as the cost-related implications of carbon taxes.
- Reduce risk – the more energy is consumed, the greater the risk that energy price increases or supply shortages could seriously affect your profitability, or even make it impossible for your business/organization to continue. With energy management we can reduce this risk by reducing your demand for energy and by controlling it so as to make it more predictable.

On top of these reasons, it’s quite likely that we have some rather aggressive energy-consumption-reduction targets that you’re supposed to be meeting at some worrying point in the near future. Our understanding of effective energy management will hopefully be the secret weapon that will enable us to meet those aggressive targets.

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