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How to violate the first law of thermodynamics with an ASE of Papain and Newcomen before it was stated by Clausius

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Abstract

This paper explores the historical and thermodynamic implications of the atmospheric steam engines (ASE) developed by Denis Papin and Thomas Newcomen in the late 17th and early 18th centuries. These engines, which operated using vacuum-induced contraction rather than steam expansion, seemingly violated the first law of thermodynamics—conservation of energy—before it was formally articulated by Rudolf Clausius in the mid-19th century. Papin's innovative approach utilized thermal contraction and atmospheric pressure to perform mechanical work, a method later refined by Newcomen. The engines achieved work through vacuum generation by condensing steam with cold water, a process that contradicted the conventional understanding of energy conservation as later defined by Clausius and Carnot. The paper analyzes the operational principles of Papin's and Newcomen's ASEs, highlighting how their contraction-based work led to an increase in internal energy while performing useful mechanical work, a phenomenon inconsistent with the first law of thermodynamics. The study also examines the transition from contraction-based engines to expansion-based systems, such as the Rankine cycle, and discusses the implications of these early engines on the development of thermodynamic theory. Through case studies and experimental evidence, the paper argues that the first law, as originally stated, fails to account for contraction-based work, suggesting a need for its revision to include such phenomena. The findings underscore the historical significance of Papin's and Newcomen's contributions to engineering and thermodynamics, while also raising questions about the completeness of classical thermodynamic principles.

Keywords: atmospheric pressure, atmospheric steam engine, contraction work, Papin, Newcomen, suction work, vacuum work.

Acronyms	***description***
ASE	*Atmospheric steam engine*
FLT	*First Law of Thermodynamics*
Symbols/units	***description***
p(bar)	pressure
q_i(kJ/kg)	specific heat in to a cycle process
q_{i12} (kJ/kg)	Input heat to cycle process 1-2
q_{i23} (kJ/kg)	Input heat to cycle process 2-3
q_o(kJ/kg)	specific heat out from a cycle process
q_{o42} (kJ/kg)	output heat from cycle process 4-2
q_{rec}	Recovered heat from cycle process 4-1
s(kJ/kg-K)	specific entropy
h(kJ/kg)	specific enthalpy
T(K)	absolute temperature
u(kJ/kg)	specific internal energy
v(m^3/kg)	specific volume
V(m^3)	volume
w(kJ/kg)	specific work
w_i(kJ/kg)	specific work in
w_o(kJ/kg)	specific work out
w_{oexp} (kJ/kg)	Output expansion work due to previously added heat for VTVT and VsVs cycles

w_{ocont} (kJ/kg)	Output contraction work due to previously extracted heat for VTVT and VsVs cycles
w_{isuct} (kJ/kg)	Output expansion work w_{o23} due to added heat for VTVT and VsVs cycles
W_{icomp} (kJ/kg)	Output contraction work w_{o41} due to extracted heat for VTVT and VsVs cycles
w_n (kJ/kg)	Net useful work ($w_{oexp} + w_{ocont}$) = ($w_{o23} + w_{o41}$)
η_{th} (%)	Cycle thermal efficiency [w_n/qi] = ([w_{oexp}/q_i] + [w_{ocont}/q_o])/ q_i
η_{th_cont} (%)	Contraction work-based Cycle thermal efficiency [w_{ocont}/q_o]

1 Introduction

Denis Papin, a pioneering physicist and inventor, made significant contributions to steam-powered machinery, laying the groundwork for the steam engine, which played a crucial role in the Industrial Revolution. Later, Denis Papin and Thomas Newcomen made significant contributions to the initial creation of the atmospheric reciprocating steam engine (ASE), which seemingly violated the first principle of thermodynamics even before it was formally stated. Based on Denis Papin's research on contraction-based work using reciprocating ASE s in 1690, Thomas Newcomen developed his patented reciprocating steam engine around 1712. Newcomen's engine operated at atmospheric pressure and performed work through contraction, achieved by condensing steam with cold water following the disruptive contributions of Denis Papin. Both Papin and Newcomen successfully utilized the concept of a vacuum and atmospheric pressure to perform contraction-based mechanical work.

Papin's groundbreaking contribution involved harnessing the potential of negative pressure (a vacuum) relative to atmospheric pressure to perform mechanical work. Unlike traditional steam engines that relied on steam expansion, Papin's approach leveraged thermal contraction. His engine pulled the piston using the vacuum generated through cooling and condensing steam with cold water.

How could Thomas Newcomen, around 1712, violate the first principle of thermodynamics with his ASE? This principle, which involves the conservation of energy, was not formally enunciated until Clausius' work around 1860. Newcomen's engine operated at atmospheric pressure, creating a vacuum through steam condensation by extracting heat.

1.1 Carnot and Clausius' Contributions: In 1834, 112 years after Newcomen, Carnot developed the ideal Carnot cycle, defining its maximum efficiency based on energy balances that obey the first law of thermodynamics, which involves the conservation of energy. Rudolf Clausius, around 1850, further established the foundations for the principle of conservation of energy, which is central to the first law of thermodynamics. As steam engine designs evolved, James Watt and Thomas Newcomen made significant advancements. Newcomen's design, primarily serving as a water pump for mines, abandoned Papin's method of mechanical work through contraction. The dominant trend shifted toward the Rankine cycle, based on steam expansion. In this cycle, the vacuum generated by condensation extended the expansion process, but the work done by contraction was no longer part of the equation.

1.2 Chronology of the historical developments

Among the first steam engines capable of producing useful mechanical work, generally intended to pump water in the coal mines of the United Kingdom, those of Thomas Savery [1-2], stand out. These have been displaced by those devised and published by Denis Papin [3], which has subsequently been developed by Thomas Newcomen [4]. Thomas Savery's engine stands out for operating at atmospheric pressure by means of a vacuum generated by cooling the steam, which was used to cause the Venturi effect, unknown at that time, which was later published by Venturi. Therefore, it was not a reciprocation steam engine that used a cylinder or piston. In contrast to Savery's engine, Papin and Newcomen used the technique based on the use of a single-acting and later double-acting reciprocating cylinders, atmospheric pressure and vacuum. The technological state of the reciprocating steam engine was later improved by James Watt [5] operating with high pressures and vacuum produced by condensation outside the cylinder.

Among the technological advances based on steam engines characterized by operating at atmospheric pressure and vacuum are the developments of Papin and, based on the same, those of Newcomen. They are particularly striking because they exhibit the characteristic of violating the first principle through the balance of energies because they operate by performing useful mechanical work by thermal contraction achieved by condensation of steam within a single-acting reciprocating cylinder. The useful mechanical work obtained by contraction stands out for being an output work that involves a reduction in volume and an increase in internal energy simultaneously. That is, useful mechanical work is obtained while internal energy is increased. This phenomenon is not considered by the first principle as stated by Clausius.

Similarly, Gerald Müller and George Parker [6-7] conducted a series of experiments to assess this theory by including a forced expansion stroke. Recently, the atmospheric steam engine (which implies that useful work is due to the presence of a vacuum) was re-evaluated. According to the authors, the theoretical efficiency of the ideal engine can be increased from 6.5% to 20%. Also, in reference [8], it was developed a thermo dynamical model of an atmospheric steam engine, yielding acceptable results. From these technologies, high-pressure and supercritical temperature steam engines were developed in Rankine cycles using the advantages of vacuum until today.

In references [9-13] the state of the art of thermal cycle technologies that allow operation with both thermal expansion and contraction, characterized by thermal cycles composed of closed processes without state changes, was presented. The fact of using closed processes has the advantage of avoiding losses due to flow work, while avoiding state changes entails avoiding losses of vaporization and condensation heats.

The advances continued and now the state of the art in this field is as follows: These machines can also operate at atmospheric pressure by being subjected to a vacuum to perform useful work based on contraction. This is possible by using double-acting reciprocating actuators, both those based on Reciprocating Double-Acting Cylinders (RDAC) and on reciprocating thermo-hydraulic systems.

Some interesting topics that has been taken into account deals with three disruptive technological challenges that must be overcome to implement efficient power units (PUs) capable of being operated by means of thermal contraction based on a vacuum under closed processes-based adiabatic-isentropic transformations, as described in [14-15] as well as optionally contraction based on strictly isothermal closed processes. The first challenge is that a thermal machine must be able to operate with the aforementioned thermal cycle (i.e., it must be capable of operating through thermal contraction). The second challenge is that the thermal cycles of a thermal machine must be able to operate with strictly isothermal processes of both thermal expansion and contraction. The third technological challenge is that a thermal machine must be able to develop highly effective forced thermal convection heat transfer media at the transfer rate required by the nominal power of each PU, where every PU is composed of a pair of RDACs equipped with associated heat transfer equipment.

Mentioned contributions were recently followed by disruptive advances on power plants composed by groups of power units coupled in cascade and conducted by thermal cycles characterized by doing work due to expansion and contraction of the thermal working fluid according to references [16-19] and [21], in which expansion has been achieved by adding heat and contraction has been achieved by extracting heat. The studies for designing and prototyping such power plants have been carried out considering real gases as working fluids. The data on the studied thermal real working fluids to be applied on the studied cases is achieved from E. W. Lemmon et al [20].

The advances are focused on improving the performance of Self-Sustaining Power Machines by using heat regeneration in the PUs, cascade heat recovery is used, thereby achieving absolutely disruptive efficiencies compared to conventional technologies. The studied cases regarding to the prototyping tasks belong to patents referenced in [22-24].

1.3 Operational Procedure of Papin’s and Newcomen’s ASE: The atmospheric pressure steam thermal cycle of Denis Papin's machine operates as follows:

During the passive movement of the piston inside the cylinder, steam is admitted at atmospheric pressure. Since the pressure on both sides of the piston is atmospheric, no work is done during steam admission. This movement is passive, driven by a counterweight attached to the water extraction pump, which pulls the piston as it admits steam.

When the piston reaches the end of its stroke and is filled with steam, cold water is injected to cool and condense the steam, generating a vacuum. The return movement of the piston, necessary for performing useful mechanical work, is then enabled.

In fact, while the Papin and Newcomen machines perform useful mechanical work by contraction followed by vacuum caused by condensation with heat extraction, i.e. cooling of the steam, the later Watt machines do mechanical work by expansion due to the addition of heat. The comparison between both modes of operation (expansion and contraction) suggests that there is a great difference in the energy balances between both concepts of heat conversion to useful work. Such difference between the two modes of operation gives rise to a great controversy in terms of energy balance. Newcomen's engine, based on Papin's designs, seemingly violated the first law of thermodynamics before Carnot and Clausius' statements. Despite its low efficiency, the engine was used industrially for over half a century to extract water from mines. Its applications ended when James Watt, with Newcomen's assistance, made significant modifications, including automation, to advance towards the Rankine cycle, which required higher steam pressure and temperature for more efficient work by expansion.

In summary, Papin's ingenious concept of extracting work from thermal contraction left a lasting impact on engineering, even though his specific design was not widely implemented. His legacy paved the way for subsequent developments that transformed industry and transportation. The consequences of such disruptive progress have two aspects: positive and negative.

Positive in terms of economic, industrial and social development.

Negative in everything related to global warming responsible for accelerating climate change and environmental pollution, at a global level.

2 The strategy to do useful work for pumping water from coal mines for more than half a century by combination of atmospheric pressure and vacuum

The chronology of the evolution of thermal engine technology experienced some disruptive changes. Thus, on the basis of Danis Papin´s research results dealing with contraction–based work carried out by means of reciprocating ASE 1690, Thomas Newcomen around 1712 developed his patented reciprocating steam engine characterized by operating at atmospheric pressure while doing work by contraction due to the vacuum achieved by condensing the steam by adding cold water. Both Papin and a bit later Newcomen used successfully the concept of a vacuum to do contraction-based mechanical work.

Later, Carnot 1834 (112 years after Newcomen) developed the ideal Carnot cycle to operate an ideal Carnot engine characterized by defining its maximum efficiency by Carnot's theorem based on an energy obeying first law, which is subject to the use of the unknown principle of conservation of energy. However, Rudolf Clausius around 1850 (16 years after Carnot) stabilized the foundations for the principle of conservation of energy, which is subject to the first law of thermodynamics.

How could Thomas Newcomen around 1712 violate the first principle of thermodynamics with his ASE doing work by contraction-based vacuum, that is, the principle of conservation of energy before being enunciated or claimed by Rudolf Clausius around 1860 by means of a reciprocating steam engine operating at atmospheric pressure through a vacuum achieved by condensation by extraction of heat?

The ASE general use has ceased to be useful because it has been surpassed in technology and efficiency by James Watt's engine, which exceeded Papin's engine in working pressure and temperature; James Watt's engine no longer used the concept of vacuum to do work by contraction, but the vacuum in Watt's engine was and continues to be used to extend the expansion.

Unfortunately, neither Carnot (1834) nor Clausius (1850) realized that there were other heat-work interactions that could increase efficiency. As a result, the Papin and Newcomen engines were abandoned and steam engines development focused on extended expansion in vacuum undergoing changes of state that entail significant inherent thermal losses.

2.1 Papin and Newcomen's ASEs: When Papin and later Newcomen developed their "atmospheric pressure" steam engines, characterized by performing mechanical work through vacuum, there were no steam tables, thermodynamic models, or calculation methods available. They relied on imagination, intuition, and experimental evidence. They faced two options for using vacuum as the core of their work:

Total Condensation: Assuming no liquid matter or wet vapor, resulting in an empty space. Thermodynamic models could not be applied due to the absence of a thermal working fluid (TWF). The work resulted from atmospheric pressure and cylinder volume.

Partial Condensation: Assuming a fraction of the wet vapor remained uncondensed, creating vapor in a vacuum state. The work depended on the amount of heat extracted to condense part of the vapor initially contained within the cylinder.

3. Papin´s ASE working principle

The technique to do useful work by an ASE by means of combining atmospheric pressure and vacuum has been successfully carried out by Papin's ASE and later transferred and taken up by Newcomen. In Fig. 1 it is shown that the work required to raising the weight and its associated pump load a distance equal to the stroke of the piston is equal to the work done by the actuating cylinder piston due the vacuum achieved by steam condensation.

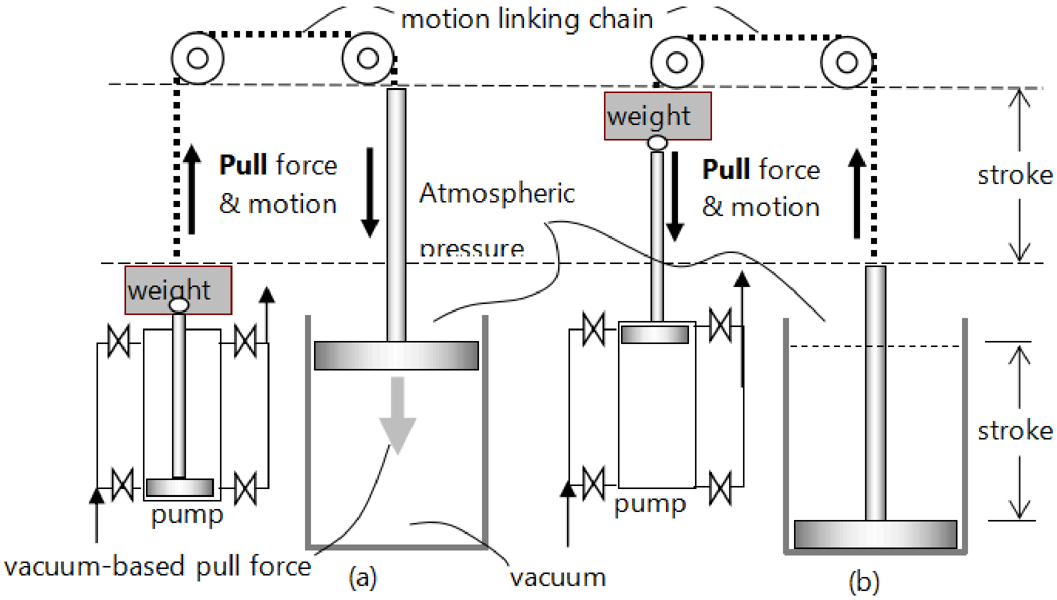

Figure 1 Work required raising the weight attached to a water pump a distance equal to the stroke of the actuating cylinder piston shown in Fig.1(a) and (b).

Let's consider the actuator consisting of a reciprocating single-acting cylinder enabled to do useful work by contraction due to a vacuum achieved by previous steam condensation. The following assumptions are considered:

1- Vacuum is generated by steam condensation into the lower cylinder chamber.

2- Contraction force consists of a pull force generated by vacuum.

As consequence of a vacuum, the cylinder piston located at the upper position, as depicted in Fig. 1(a), is displaced to the lower position, as depicted in Fig. 1(b), due to the vacuum existing into the lower cylinder chamber as a closed and adiabatic process.

The following two optional strategies regarding to doing contraction work can be applied to do useful work:

1--Complete condensation and purge of liquid water without traces of water inside the lower chamber of the cylinder,

2--Partial condensation and purge of liquid water inside the lower chamber of the cylinder.

3.1 The operating mode of Papin´s ASE with total condensation

In the case of a complete condensation and purge of liquid water without traces of water inside the lower chamber of the cylinder the operation mode is as follows:

The work done as consequence of a vacuum is equal to the product of the atmospheric pressure and cylinder vacuum chamber volume. Assuming total condensation, since there is no water atoms left inside the lower chamber of the cylinder in a state of absolute or pure vacuum, the contraction process does not encounter a working fluid to oppose the contraction effect. This suggests that during contraction the vacuum continues at zero pressure, and therefore the contraction force is that which corresponds to atmospheric pressure and is constant throughout the piston stroke. Since no thermal working fluid is involved in the contraction process, then, no such heat-work interaction exist, but pure mechanics because this process doesn't involve heat, but only pressure and volume. Therefore the work done under a total condensation is given as

$$w_{o\,cont} = F_{pull} \cdot St = p_{atm} \cdot A \cdot St = p_{atm} \cdot V_{cyl} \tag{1}$$

The following notation is used in Eq. (1): w_{ocont} is the contraction work, F_{pull} is the force on the cylinder piston, St is the stroke or piston displacement, p_{atm} is the atmospheric pressure, A is the cylinder cross-section area and V_{cyl} is the lower cylinder chamber volume

3.2 The operating mode of Papin´s ASE with partial condensation

In the case of partial condensation and purge of liquid water inside the lower chamber of the cylinder the operation mode is as follows: The work done is the change of its internal energy, which ends when weight and steam forces are equal —equilibrium state—.

First law applied on a closed process through an energy balance applied on a heat-work interaction yields:

$$\sum q + \sum w - \Delta u = 0 \qquad 2$$

Eq. (2) assumed as a closed process includes input heat, output heat, input work, output work and an internal causal effect assumed as internal energy. That is,

$$q_i + w_i - q_o - w_o - \Delta u = 0 \qquad 3$$

Assuming the concerned heat-work interaction consists of an adiabatic closed contraction,

$$q_i = w_i = q_o = 0 \qquad 4$$

The remaining variables are internal energy and useful output work, then, (3) yield

$$- w_o - \Delta u = 0 \ or - w_o = \Delta u$$

$$or \ w_o = -\Delta u \qquad 5$$

Following the energy balance based on first law, from (5) it is deduced that the energy balance is not consistent with first law since (5) indicates that the output useful work corresponds to a decrease of internal energy, that is $w_o = -\Delta u$

However, the experimental observations validated along more than half a century, show that

1 internal energy increased,

2 output useful mechanical works has been done, and

3 internal energy increases simultaneously while output useful mechanical work is being done by contraction

Consequently the observed results differ from (5) in that the real fact is

$$w_o = \Delta u \qquad (6)$$

The controversy lies in that if we compare Eq. (5) based on the first law of thermodynamics —law of conservation of energy— with Eq. (6) derived from experimental observations on atmospheric pressure-based steam engines of Papin and Newcomen, it turns out that they are absolutely contradictory. First, since the experimental results are irrefutable, then the first law as currently found is incomplete due to the following types of mechanical work.

The observed results based on experimental evidence are:

The effect of output useful contraction work w_{ocont}

$$w_{ocont} = \Delta u \qquad (7)$$

The effect of input suction work w_{isuct}

$$w_{isuct} = -\Delta u \qquad (8)$$

Therefore, the first law, as stated so far:

1 does not consider the effects of useful output work done by contraction w_{ocont} due to the vacuum achieved by cooling through heat extraction.

2 Similarly, it does not consider the effects of input work applied to the cylinder causing suction due to vacuum achieved by cylinder volume expansion through work applied w_{isuct}.

Based on the controversial results derived from energy balances based on the first principle, it is necessary to take into consideration the types of work both input, which leads to the invalidation of Eq. (2). That is:

$$\sum q + \sum w - \Delta u \neq 0 \ \text{ or } \ \sum q + \sum w \neq \Delta u \qquad (9)$$

3.3 Discussion

The first law of the thermodynamics — a conservation law— applied on a closed process states that:

if mechanical work is added to a process, its internal energy should increase, while

if useful work from the process is obtained, then, its internal energy should decrease.

The reality with respect to the work obtained by contraction show us that when obtaining useful work in a contraction process, the internal energy increases instead of decreasing. This controversial experimental observation during more than half a century of operation of the ASEs created by Papin and Newcomen violated the first principle even though it had not been stated by Clausius.

The observed experimental fact by which *internal energy increases while useful work is done, is in disagreement with the first law.*

This means that the conservation law, as assumed firstly by Carnot in order to propose his Carnot theorem, and later stated by Clausius is not fulfilled when contraction work is involved.

This means that in the energy balance a contraction work instead of a generic work —expansion work— should be considered.

Such an ASE characterized by operate successfully more than half a century, used a contraction heat-work interaction responsible for defying the first law of the thermodynamics stated by Clausius, statement that is not complete since do not consider contraction work.

The energy balance previously assumed by Carnot to formulate his Carnot theorem and later stated in a general way by Clausius considers that both the input and output heat of a closed process interact with two types of mechanical work:

-- input work, or work added to the process and,

-- output work or useful obtained work.

It is assumed that:

--the input work contributes to the increase of the internal energy of the process, while

--the output work or useful work contributes to the decrease of internal energy.

The energy balance previously assumed by Carnot to formulate his Carnot theorem and later stated in a general way by Clausius considers that both the input and output heat of a closed process interact with two types of mechanical work:

--input work, or work added to the process and

--output work or useful work obtained from the process.

Since the statement of the first law, it has been conventionally assumed and continues to be assumed that:

--The input work —the mechanical work added to a process— contributes exclusively to the increase of the internal energy of the process, while

--The output work —the mechanical work obtained from a process or useful work— contributes exclusively to the decrease of internal energy.

Evidence from observations of the mode of operation of Papin's and Newcomen's engines over more than half a century concludes that Papin's and Newcomen's ASEs do not obey the energy balance established by the first law.

The real fact is:

1--The output useful work w_{ocont} —mechanical work done by contraction due to vacuum previously obtained by cooling the steam with heat extraction from a process— done by Papin´s and Newcomen´s ASEs is achieved while internal energy increases, which violates the energy balance such as it stated by the first law.

2--The input work w_{isuct} —mechanical work added to generate vacuum into the cylinder— contributes to decrease slightly the steam pressure and its internal energy into the cylinder consisting of an expansion, which violates the energy balance such as is stated by the first law.

To reinforce the discussion on the influence of certain heat-work interactions on the principle of conservation of energy, Fig. 2 is included to reinforce the consistent and reasoned arguments on the validity of irrefutable experimental observations. Furthermore, the influence between heat-work interactions, energy balance and first law applied on closed processes is highlighted

The main objective illustrated in Fig. 2 is to observe that on the basis of experimental-based evidence not only by laboratory experiments but due to more that 50 years of Pain-Newcomen reciprocating ASEs operating to extract water from coal mines:

1 The case of expansion and compression illustrated in Fig 2 (a), (b) and (c), fulfills the first law such as stated by Clausius. However,

2 The case of contraction and suction depicted in Fig 2 (d), (e) and (f), do not fulfill the first law as stated by Clausius.

Therefore, in order to be useful and rigorous, this irrefutable fact only suggest us that tea first law such as was stated by Clausius should be corrected which includes modified, and amplified to represent in general the real facts.

According to the information provided by Fig. 2, the consequences of energy transfer which includes heat and work interactions undergoing contraction or suction does not obey first law. Therefore, (a), illustrates that the single-acting cylinder showing the I/O energies involved —heat and work transfer— is characterized by satisfying the fist law while manipulating useful work by **push forces**.

(b), illustrates the closed process-based heat-work interactions characterized by satisfying fist law, where input energies —heat and compression works— contributes on increasing internal energy while output energies —heat and expansion works— contributes on decreasing internal energy. (c), illustrates the energy balance based on first law, characterized by fulfilling first law.

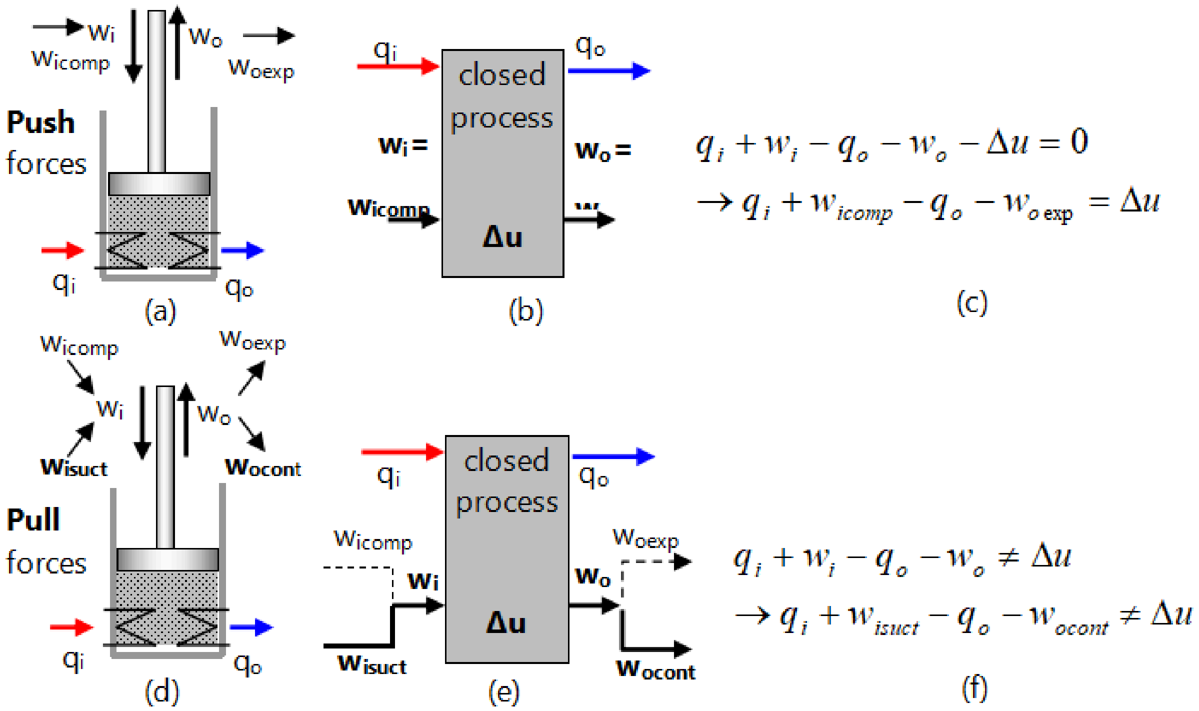

Figure 2. Heat-work interactions in closed process mode likely to occur in a single-acting reciprocating cylinder-based actuator.

However, (d) illustrates how the single-acting reciprocating cylinder shows that the I/O energies involved —heat transfer and work— characterized by contraction and /or suction like work, while manipulating useful work by **pull forces**, do not obey, opposes or violates the first law. (e), illustrates the closed process-based heat-work interactions characterized by violating the first law, where input energies —heat and suction works— contributes on decreasing internal energy while output energies —heat and contraction works— contributes on increasing internal energy. (f), illustrates the energy balance based on first law, which is affected by work interaction such as suction or contraction is characterized by violating first law.

According to the energy balance based on first law, depicted in Fig. 2(c), follows that:

1 All input energy interactions —heat or work— contributes to increase internal energy

2 All output energy interactions —heat or work— contributes to decrease internal energy

Pull forces derived from heat work interactions involving suction or contraction wok violate first law according to experimental observations:

1 The heat-work interactions represented by its energy balance illustrated in Fig. 2 (a), (b) and (c) fulfill the first law. That is

$$q_i + w_i - q_o - w_o - \Delta u = 0$$
$$\rightarrow q_i + w_{icomp} - q_o - w_{o\exp} = \Delta u \qquad (10)$$

2 However the heat-work interactions depicted in the energy balance illustrated in Fig. 2 (d), (e) and (f) do not fulfill the first law. That is

$$q_i + w_i - q_o - w_o \neq \Delta u$$
$$\rightarrow q_i + w_{isuct} - q_o - w_{ocont} \neq \Delta u \qquad (11)$$

Table 1 Experimental observation about some useful heat-work interactions concerning expansion and compression modes: contraction and suction

I/O force and work	Force type	I/O w type	U change	Observed first law fulfillment	raw
Input forces Input work, w_i	Push force	w_{icomp}	Δu		1
	Pull force	w_{isuct}	- Δu	**inconsistent** with first law	2
Output forces output work, w_o	Push force	w_{oexp}	- Δu		3
	Pull force	w_{ocont}	Δu	**inconsistent** with first law	4

A common characteristic of contraction and suction-based heat-work interactions is that while expansion and compression-based push forces are consistent with the first law, contraction and suction-based pull forces are not consistent with first law. This characteristic is interesting because the forward and the backwards strokes of Papin´s ASEs operate by means of pull forces as depicted in Figs 1 and 3 and consequently, violating the first law. Every cycle consists of an active forward stroke conducted by vacuum giving rise to contraction that exerts a pull force on the load –typically a stripping pump– and a passive backwards stroke conducted by suction force giving rise to a pull force on the piston to return towards the initial cycle position.

Summarizing, assuming processes that involve heat-work interaction dealing with contraction and suction works, the differences between the energy balances formulated according to the first law given as $q_i + w_i - q_o - w_o = \Delta u$ and the experimental results shown in the table 1 lie in the fact that the equation describing the energy balance (c), considers that the incoming work contributes to the increase of the internal energy and the outgoing work contributes to the decrease of the internal energy.

To conclude, a flagrant controversy with the first law exists since this is false according experimental observations depicted in Table 1, rows 2 and 4 and more than 50 years of experimental validation by the Papin–Newcomen ASE operating successfully. This means that as depicted in Table 2, the energy balances of **heat-work-force** interactions depicted should be taken into account to modify the frost law according the real facts. Considering closed processes, the theoretical and experimental evidence can definitely be highlighted as the following general statements also illustrated with Table 2:

Table 2 Energy balance (EB) of closed-process (CP)-based **heat-work-force** interactions

First law (FL)-based CP EB	Adiabatic CP model	FL agreement	force types
$q_i - q_o + w_{icomp} - w_{o\exp} = f(\Delta u)$	$w_{icomp} - w_{o\exp} = f(\Delta u)$	***fulfill*** first law	***Push*** forces
$q_i - q_o - w_{ocont} \neq f(\Delta u)$	$-w_{ocont} \neq f(\Delta u)$	***don't fulfill*** first law	***Pull*** forces
$q_i - q_o + w_{isuct} \neq F(\Delta u)$	$w_{isuct} \neq \Delta u$	***don't fulfill*** first law	***Pull*** forces
$q_i - q_o + w_{isuct} - w_{ocont} \neq f(\Delta u)$	$w_{isuct} - w_{ocont} \neq f(\Delta u)$	***don't fulfill*** first law	***Pull*** forces

Heat-work interactions with expansion and/or compression works **fulfill** the first law

Heat-work interaction with expansion and/or compression works involve **pull** forces

Heat-work interactions with suction and/or contraction works **don't** fulfill first law

Heat-work interactions with suction and/or contraction works involve **push** forces

Therefore, the influence of the force types on the internal energy of a closed system is important in such a way that.

The essential condition for the energy balance of a closed system to satisfy the first principle of thermodynamics is that **all interacting forces are push forces**.

As a consequence:

Any energy balance affected by pulling (suction or contraction) forces violates the first principle of thermodynamics as stated by Clausius.

4. Detailed Papins´s ASE structure and operational strategy

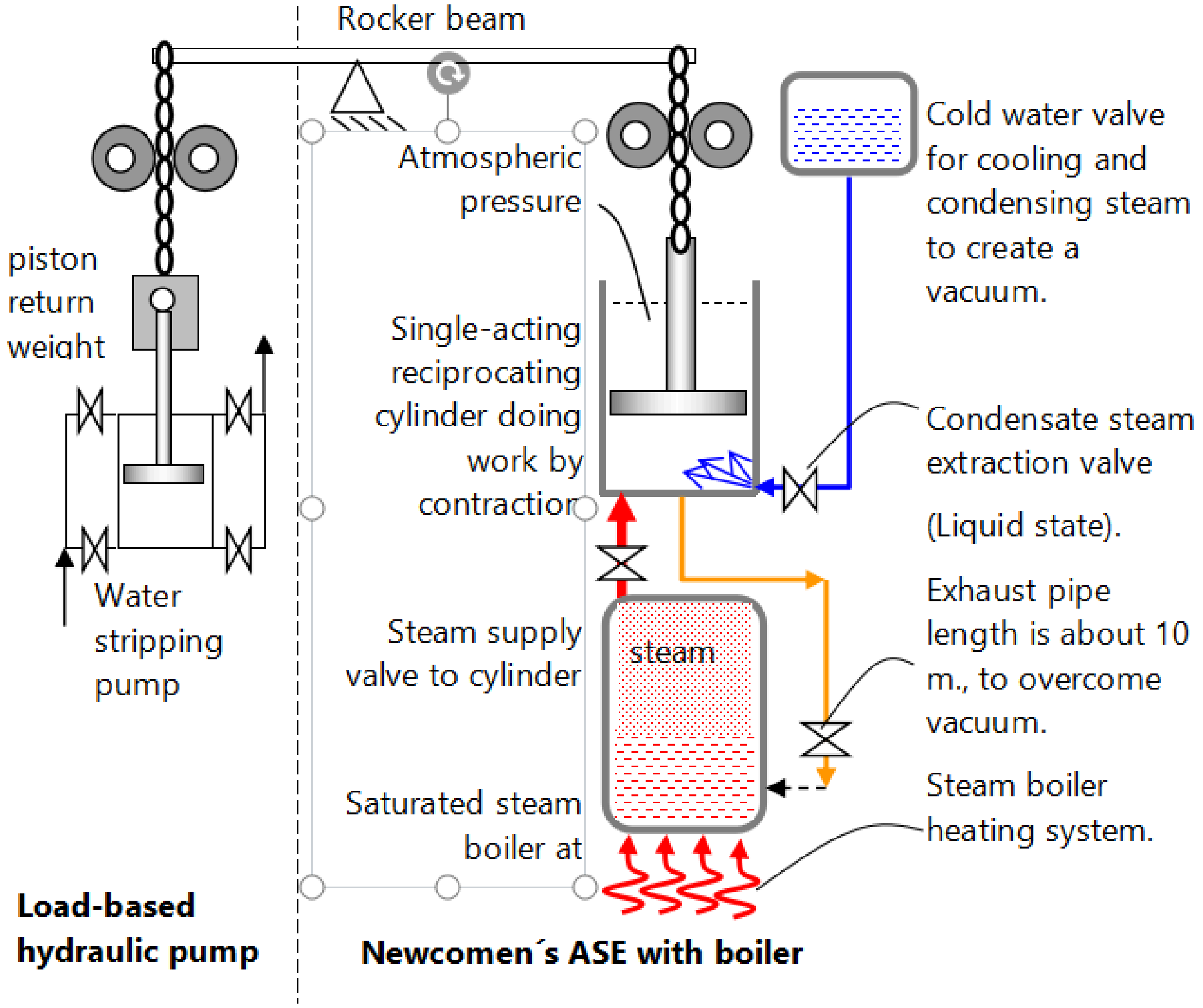

Figure 3 Illustration of the structure of the Papin-Newcomen ASE.

Fig. 3 illustrates the layout of a simplified Papin´s ASE structure. It is worth noting how the chains that connect the cylinder rod to the water pump transmit traction forces instead of propulsion forces. The traction forces are caused by the vacuum and are used both to achieve work by contraction, which is responsible for increasing the internal energy, and to perform traction work to achieve suction based on expansion, which contributes to the decrease of the internal energy while facilitating the admission of wet steam into the cylinder.

The most important accessories of the steam engine include:

--The load associated with the machine, which consists of a water extraction pump equipped with a counterweight to facilitate the return stroke of the pump,

-- The single-acting reciprocating cylinder equipped with a rod and piston,

--a steam boiler operating at atmospheric pressure,

-- lever and chains for transmitting the movement of the piston to the water pump and,

-- cold water injection devices for steam condensation.

4.1 Approaching an ideal modeling task of the Papin´s-Newcomen´s ASEs

As depicted in Fig. 4, the only useful work is performed by contraction due to the vacuum obtained by condensation of the steam. A fraction of the useful work is used to activate the pump to extract water, while the remaining fraction is used to lift a weight used to return the piston during its passive return stroke.

According to the illustration of Fig 4 the T-s and p-V diagrams of the Papin´s-Newcomen´s thermal cycle operates through the following processes:

Heating (1-2): Sensible heat is added to the liquid water at constant pressure.

Heating (2-3): Latent heat is added to the water to produce steam at atmospheric pressure. The boiler valve is opened to fill the cylinder passively at atmospheric pressure, without doing work, as the pressure on both sides of the piston is equal, resulting in no piston force. During this process piston returns backward forced by a counter-weight located at the extreme of a beam that connects the piston rod with the load-based weight according to Fig. 1

Condensation (3-4): Isochoric condensation occurs by cooling the steam with cold water, creating a vacuum.

Work by contraction (4-2): Adiabatic-isentropic contraction work is performed due to the vacuum achieved by the previous condensation of the steam.

Heat addition undergoes sensible heat and latent heat. Since it is an open processes enthalpies are accounted.

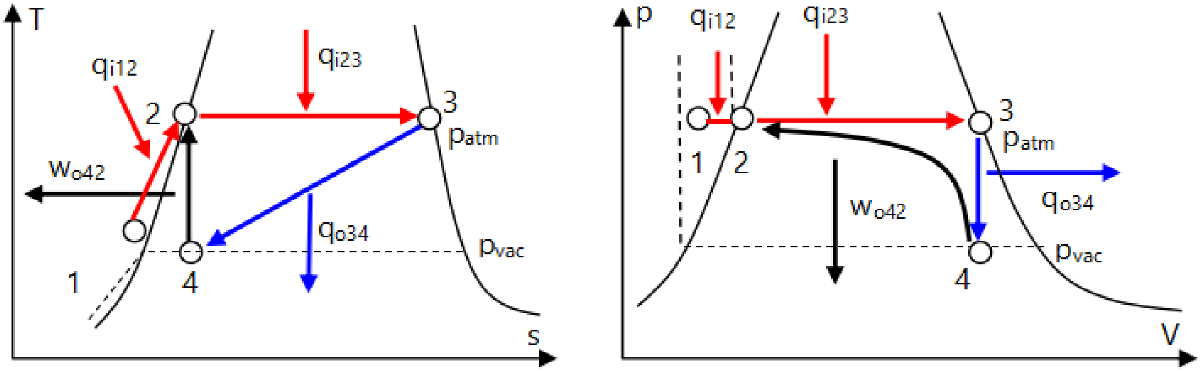

Figure 4 Approach to the T-s and p-V Papin-Newcomen´s steam engine ideal cycles with partial condensation

Work by suction (2-1): During the returning stroke of the piston a slightly returning force is exerted by the counter-weight to bring the piston to the initial position. This consists of a suction force which contributes slightly to decrease the input steam temperature into the cylinder active side, which will be neglected in the analysis due to the low effect on the results.

$$q_i = q_{i13} = q_{i12} + q_{i23} = h_3 - h_1 \tag{12}$$

$$q_{o34} = u_3 - u_4 \tag{13}$$

$$w_{o42} = u_2 - u_4 \tag{14}$$

the active stroke of doing active and useful work by contraction due to vacuum is completed at the end of the stroke in state 2, ending the cycle. The transition between states 2 and 1 involves a thermodynamic discontinuity, during which there is no activity inherent to the thermal cycle.

A new cycle begins in 1, supplying sensible heat, followed by latent heat and addition of moist steam to the cylinder, with the help of the suction force exerted by the piston when requested by the counterweight attached to the pump.

4.2 Ideal performance evaluation of the Papin´s-Newcomen´s atmospheric steam cycles

Since the only useful work consists of a contraction-based work the general energy balance don't satisfy the energy balance based on the conventional first law. That is,

$$q_i - q_o \neq w_o \quad \text{or} \tag{15}$$

$$q_{i12} + q_{i23} - q_{o34} \neq w_{o42} \tag{16}$$

According to Eq. (3) to (9) and (12) to (14), the thermal efficiency (η_{th}) with regard to the total added heat is the ratio of the useful work (w_{o42}) to the total added heat (q_{i13}), so that,

$$\eta_{th}(\%) = 100 \cdot \frac{w_{o42}}{q_{i13}} \tag{17}$$

5 Case studies

The proposed case study considers 8 cases corresponding to the ASE —created sad designed by Papin and further improved and patented by Newcomen— under different condensing temperatures. Throughout the study, the influence of the degree of condensation (given by the cooling temperature) on thermal efficiency is highlighted.

The case study is interesting because it allows us to visualize how useful work is done by thermal contraction using tensile forces, how work is done to return the piston to its initial state by means of suction work that corresponds to tensile forces, and how both heat-work interactions violate the first principle of thermodynamics before it was stated by Clausius.

It is also worth highlighting the vacuum utilization strategy to obtain useful mechanical work by contraction. It consists of useful work by contraction characterized by the fact that it does not fit into the energy balance formulated by the first principle. The same occurs with the suction work applied to return the piston to the cycle start point. This work is insignificant and therefore has not been taken into account in this analysis.

Table 3. Analysis of data corresponding to T-s and p-V diagrams depicted in Fig. 4.

State points	T(K)	p(bar)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg-K)
Test 1 - water						
1	280.00	1.01325	0.00100	28.79	28.897	0.104
2	374.00	1.01325	0.00104	424.66	424.78	1.3222
3	374.00	1.01325	1.59950	2508.40	2677.7	7.3383
4	280.00	-0.99933	17.62500	347.67	365.16	1.3054
Test 2 - water						
1	290.00	1.01325	0.00100	70.72	70.825	0.251
2	374.00	1.01325	0.00104	424.66	424.78	1.3222
3	374.00	1.01325	1.59950	2508.40	2677.7	7.3383
4	290.00	-0.99405	8.64970	359.82	376.43	1.3054
Test 3 - water						
1	300.00	1.01325	0.00100	112.54	112.75	0.393
2	374.00	1.01325	0.00104	424.66	424.78	1.3222
3	374.00	1.01325	1.59950	2508.40	2677.7	7.3383
4	300.00	-0.97788	4.38920	370.73	386.26	1.3054
Test 4 - water						
1	310.00	1.01325	0.00101	154.34	154.45	0.530
2	374.00	1.01325	0.00104	424.66	424.78	1.3222

3	374.00	1.01325	1.59950	2508.40	2677.7	7.3383
4	310.00	-0.95094	2.28150	380.48	394.69	1.3054
Test 5 - water						
1	320.00	1.01325	0.00101	196.13	196.34	0.663
2	374.00	1.01325	0.00104	424.66	424.78	1.3222
3	374.00	1.01325	1.59950	2508.40	2677.7	7.3383
4	320.00	-0.90779	1.20170	389.11	401.78	1.3054
Test 6 - water						
1	330.00	1.01325	0.00102	237.95	238.15	0.791
2	374.00	1.01325	0.00104	424.66	424.78	1.3222
3	374.00	1.01325	1.59950	2508.40	2677.7	7.3383
4	330.00	-0.84112	0.63218	396.69	407.57	1.3054
Test 7 - water						
1	340.00	1.01325	0.00103	279.82	279.93	1.038
2	374.00	1.01325	0.00104	424.66	424.78	1.3222
3	374.00	1.01325	1.59950	2508.40	2677.7	7.3383
4	340.00	-0.74137	0.32485	403.26	412.09	1.3054
Test 8 - water						
1	350.00	1.01325	0.00102	321.73	321.84	0.916
2	374.00	1.01325	0.00104	424.66	424.78	1.3222
3	374.00	1.01325	1.59950	2508.40	2677.7	7.3383
4	350.00	-0.59643	0.15625	408.87	415.38	1.3054

In Table 3 can be observed that for each case under study the condensation temperature T_1 (K) is increased into the range of 280-350 K. The result is that as tempera5ture increases the work none decreases and consequently the efficiency decreases also.

The results shown in Table 4, derived from the eight case studies considered in Table 3, include the following parameters: T_1 (K), (T_1-T_2) (K), $q_{i13}=h_3-h_1$ (kJ/kg), $q_{o34} = h_{3-}h_4$ (kJ/kg), $(q_{i13}-q_{o34})$ (kJ/kg), w_{ocont} (kJ/kg), vacuum (bar) and η_{th_cont} (%). For each case, the corresponding data set is presented. The comparison of these data allows us to obtain data trends and draw useful conclusions under a consistent analysis.

Table 4 Results obtained from the data analysis of the 8 case studies considered

Test No	1	2	3	4	5	6	7	8
T_1 (K)	280.00	290.00	300.00	310.00	320.00	330.00	340.00	350.00
(T_1-T_2) (K)	94.00	84.00	74.00	64.00	54.00	44.00	34.00	24.00
$q_{i13}=h_3-h_1$ (kJ/kg)	2648.80	2606.88	2564.95	2523.25	2481.36	2439.55	2397.77	2355.86
$q_{o34}=h_3-h_4$ (kJ/kg)	2312.54	2301.27	2291.44	2283.01	2275.92	2270.13	2265.61	2262.32
$(q_{i13}-q_{o34})$ (kJ/kg)	488.07	458.30	427.28	395.33	362.07	327.84	292.63	256.33
w_{ocont} (kJ/kg)	76.99	64.84	53.93	44.18	35.55	27.97	21.40	15.79
Vacuum (bar)	-0.99933	-0.99405	-0.97788	-0.95094	-0.90779	-0.84112	-0.74137	-0.59643
η_{th_cont} (%)	3.56	3.02	2.52	2.08	1.68	1.32	1.02	0.75

Observing Table 4, it can be seen that the temperature range of the cycle (T_1-T_2) responsible for the thermal efficiency -characterized by being dramatically low- exhibits a great dependence not only on the temperature range (T_1-T_2) applied but also varies in accordance with the vacuum reached, so that the vacuum exerts a great influence on the useful work obtained by traction forces generated by the vacuum due to the cooling and condensation of the steam giving rise to thermal contraction. This concept is illustrated in the Fig. 5, which shows the effect of a vacuum on the thermal efficiency achieved by doing work by contraction (under pull forces). The same concept has been depicted with Fig. 6, in which the dependence of the vacuum on the lowest temperature of the steam has been shown.

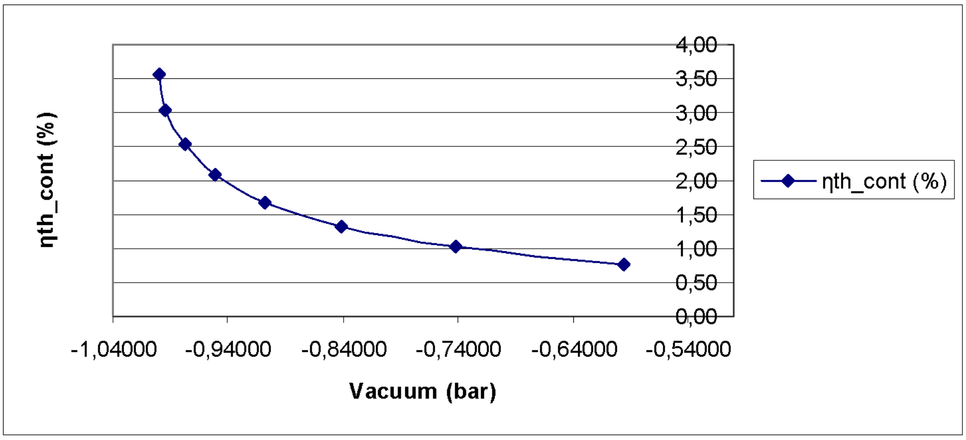

Figure 5 Thermal efficiency with regard to the contraction-based work as function of the vacuum.

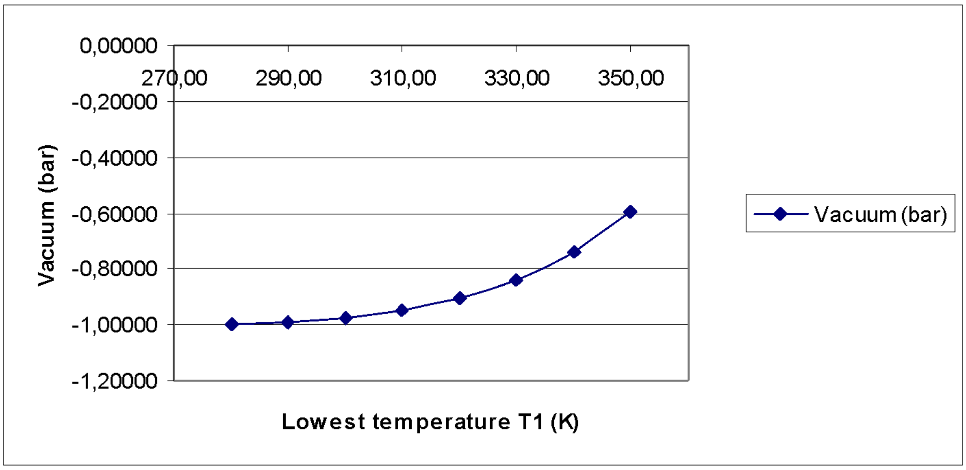

Figure 6 Vacuum as function of the temperature T1

Figure 6 illustrates the effect of increasing condensation temperature on vacuum. Vacuum increases as condensation temperature decreases.

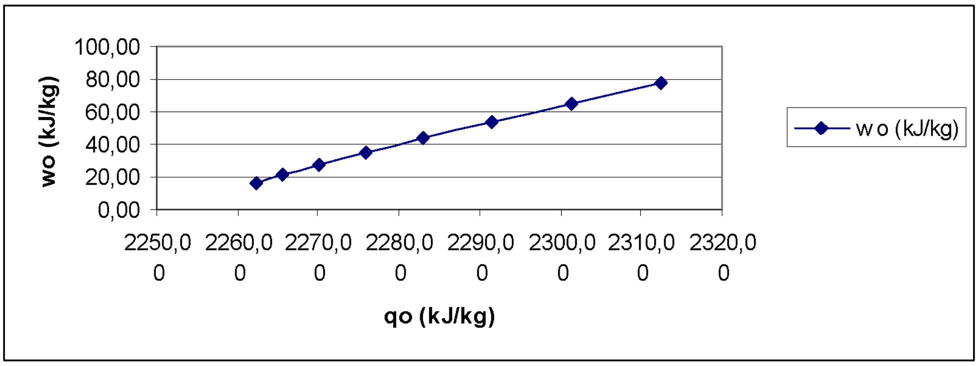

Figure 7 Useful mechanical works as function of the extracted heat q_o

Since the added heat qi is used to generate steam at atmospheric pressure, the work obtained is due to the heat extracted by cooling and further condensing the steam, so that the work achieved is due exclusively to the contraction process due to the extracted heat. This process involves an increase in internal energy since it corresponds to a decrease in volume, and yet it is a useful output work. Fig 7 illustrates the useful mechanical work w_o, as a function of the amount of extracted heat q_o. In the curve it is observed that some proportionality between work and extracted heat is approached.

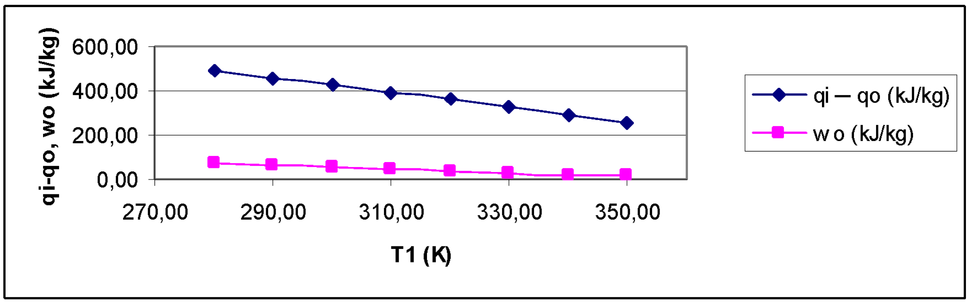

Figure 8 Input-output heat difference and useful mechanical work as function of the lowest temperature T_1

Fig 8 illustrates the comparison between Input-output heat difference and useful mechanical work as function of the lowest temperature T_1. In order to fulfill first law, the difference between input and output heats should be equal to the output useful work. Thus in Fig. 8 it is shown that there is a significant or substantial difference between both parameters. This suggests us that the first law doesn't fulfill in all studied cases. As explained, this is due to the effect of pull forces generated by suction and contraction.

6 Analysis and discussion of results

The first law of thermodynamics, a conservation law, applied to a closed process states that:

1 If mechanical work is added to a process, its internal energy should increase.

2 If useful work is obtained from the process, its internal energy should decrease.

However, the reality observed in contraction processes shows that when useful work is obtained, the internal energy increases instead of decreasing. This controversial experimental observation, noted during more than half a century of operation of the ASEs created by Papin and Newcomen, violated the first principle, even though it had not yet been stated by Clausius.

The observed experimental fact that internal energy increases while useful work is done contradicts the first law. This implies that the conservation law, as initially assumed by Carnot to propose his Carnot theorem and later stated by Clausius, is not fulfilled when contraction work is involved. Therefore, in the energy balance, contraction work should be considered instead of generic work (expansion work).

The ASEs, which operated successfully for more than half a century, used a contraction heat-work interaction that defied the first law of thermodynamics as stated by Clausius. This statement is incomplete as it does not consider contraction work.

The energy balance previously assumed by Carnot to formulate his Carnot theorem, and later stated in a general way by Clausius, considers that both the input and output heat of a closed process interact with two types of mechanical work:

1 Input work or work added to the process.

2 Output work, or useful work obtained from the process.

It is assumed that:

1 Input work contributes to the increase of the internal energy of the process.

2 Output work, or useful work, contributes to the decrease of internal energy.

Since the statement of the first law, it has been conventionally assumed and continues to be assumed that:

1 Input work (mechanical work added to a process) contributes exclusively to the increase of the internal energy of the process.

2 Output work (mechanical work obtained from a process or useful work) contributes exclusively to the decrease of internal energy.

Evidence from observations of the operation of Papin's and Newcomen's engines over more than half a century concludes that these ASEs do not obey the energy balance established by the first law. The real facts are:

1 The output useful work w_{ocont} (mechanical work done by contraction due to vacuum previously obtained by cooling the steam with heat extraction from a process) done by Papin's and Newcomen's ASEs is achieved while internal energy increases, which violates the energy balance as stated by the first law.

2 The input work w_{isuct} (mechanical work added to generate vacuum into the cylinder) contributes to decreasing the internal energy increment of volume into the cylinder or expansion, which violates the energy balance as stated by the first law.

To conclude, a flagrant controversy with the first law exists since this is false according experimental observations depicted in Table 1, rows 2 and 4 and more than 50 years of experimental validation by the Papin-Newcomen ASE operating successfully. This means that as depicted in Table 2, the energy balances of **heat-work-force** interactions depicted should be taken into account to modify the frost law according the real facts. For closed processes the theoretical and experimental evidence can definitely be highlighted as following general statements:

Heat-work interactions involving expansion and/or compression works **fulfill** the first law

Heat-work interaction involving expansion and/or compression works involve **pull** forces

Heat-work interactions involving suction and/or contraction works **don't** fulfill first law

Heat-work interactions involving suction and/or contraction works involve **push** forces

The essential condition for the energy balance of a closed system to satisfy the first law of thermodynamics is that all interacting forces (both input and output) are push forces.

Therefore, any energy balance affected by pull forces (both input and output) violates the first law of thermodynamics.

Fig. 9 it is illustrates the effect of pull forces according to the following description: (a), depicts the energy balance formulation based on first law statement. (b) depicts the pull force created by a counterweight consisting of a suction input force and work. (c), depicts pull force, created by a vacuum consisting of a contraction output force and work. The vacuum has been previously achieved by cooling a working fluid.

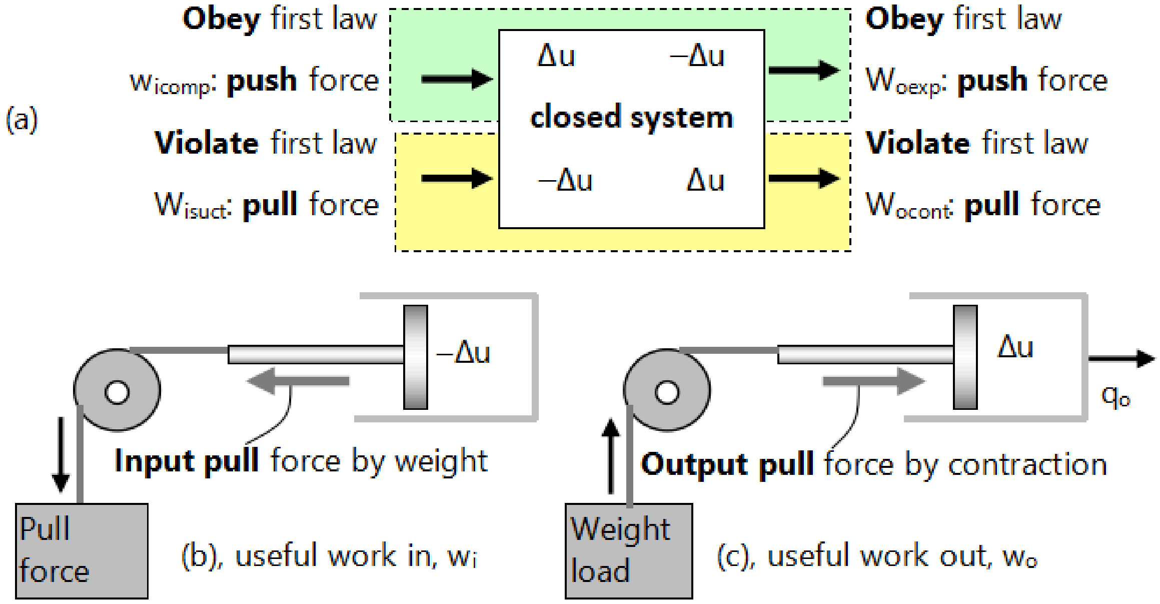

Figure 9 Illustration of the observation of everyday behavior of a single-acting reciprocating cylinder to verify that the energy balance of closed system-based heat-work interactions involving pull forces violates first law.

Furthermore, Fig. 9 illustrates that the energy balance of closed system-based heat-work interactions involving pull forces violates first law as observed by the following experimental facts:

Fig. 9(b) an input pull force creates suction effect and a vacuum while decreasing internal energy.

Fig. 9 (c) a vacuum obtained previously by extracting heat creates a pull force tat contributes to increasing the internal energy.

Summarizing, evidence based on observation of experimental facts in closed processes:

When work is done on a system through suction (increasing volume), the internal energy of the system decreases.

Conversely, when work is done on a system through compression (decreasing volume), the internal energy of the system increases.

However, when work is done by a system through contraction (decreasing volume), the internal energy of the system increases.

Conversely, when work is done by a system through expansion (increasing volume), the internal energy of the system decreases.

- Work done through suction contributes to a decrease in internal energy.

- Work done through contraction contributes to an increase in internal energy.

Therefore:

- Closed processes involving suction-work or contraction-work include pull forces.

- Closed processes involving compression-work or expansion-work include push forces.

As a result:

- Energy balances that incorporate pull forces violate the First Law of Thermodynamics (FLT).

- Energy balances involving closed processes based on suction-work or contraction-work violate the FLT.

- Energy balances involving closed processes based on compression-work or expansion-work fulfill the FLT.

In general: Closed process-based energy balances that include mechanical work performed by pull forces violate the FLT assumed as stated so far and consequently the law of energy conservation.

7 Conclusions

The research presented in this paper delves into the historical and thermodynamic implications of the atmospheric steam engines (ASE) developed by Denis Papin and Thomas Newcomen, which seemingly violated the first law of thermodynamics—conservation of energy—before it was formally articulated by Rudolf Clausius. The study highlights how these early engines, which operated through vacuum-induced contraction rather than steam expansion, achieved mechanical work in a manner inconsistent with the classical understanding of energy conservation. Therefore, key findings from the analysis include:

7.1. Contradiction of the First Law: Papin's and Newcomen's ASEs performed useful mechanical work through contraction, a process that increased internal energy while simultaneously producing work. This phenomenon directly contradicts the first law of thermodynamics, which posits that useful work output should result in a decrease in internal energy. The experimental evidence from over half a century of operation of these engines supports this contradiction, suggesting that the first law, as originally stated, is incomplete.

7.2. Role of Pull Forces: The study identifies that the energy balance in these engines is influenced by pull forces (suction and contraction) rather than push forces (expansion and compression). While push forces align with the first law, pull forces do not, leading to violations of the energy conservation principle. This distinction underscores the need to revise the first law to account for contraction-based work.

7.3. Historical Significance: The ASEs of Papin and Newcomen, despite their low efficiency, were groundbreaking in their use of atmospheric pressure and vacuum to perform mechanical work. Their designs laid the foundation for later advancements in steam engine technology, even though their contraction-based approach was eventually overshadowed by expansion-based systems like the Rankine cycle.

7.4. Implications for Thermodynamic Theory: The findings suggest that the first law of thermodynamics, as currently formulated, does not fully capture the energy dynamics of contraction-based work. These calls for a reevaluation of classical thermodynamic principles to incorporate the effects of pull forces and contraction work, which could lead to a more comprehensive understanding of energy conversion processes.

7.5. Technological Evolution: The transition from contraction-based engines to expansion-based systems marked a significant shift in steam engine design. However, the study argues that the abandonment of contraction-based work may have overlooked potential efficiencies and alternative thermodynamic pathways that could be revisited in modern engineering contexts.

In conclusion, this research challenges the completeness of the first law of thermodynamics by demonstrating how early steam engines operated in ways that defied classical energy conservation principles. The findings not only highlight the historical ingenuity of Papin and Newcomen but also call for a reexamination of thermodynamic theory to account for contraction and suction-based work types. This could pave the way for new innovations in energy conversion technologies, potentially leading to more efficient and sustainable engineering solutions.

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