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New industrial chemical heat pump from Qpinch

Wouter Ducheyne[1a], Chris Stevens[c], Steve Bonte[a], Simon Rousseau[a],

Evert van der Pol[b]

[a]Qpinch, Ankerrui 9, 2000 Antwerp, Belgium
[b]*Process Design Center, Catharinastraat 21-F, NL-4811 XD Breda, The Netherlands*
[c] *Prof. Dr. ir. Christian Stevens, SynBioC Research Group Department of Sustainable Organic Chemistry and Technology Faculty of Bioscience Engineering - Ghent University*

Abstract

Climate change and natural resource depletion have become a global priority. An enormous potential of energy is currently being wasted in industrial processes. With Qpinch's new ICHP, massive process improvements in existing and future industrial assets can be realized whilst also fostering both prosperity and the environment. Due to the uniqueness of the technology about 50% of a customer's heat consumption can be saved.

The use of inorganic oxoacids and its salts and water offers exceptional temperature lifts due to the unique low heat capacity of these components. This enables the ICHP to transform the waste heat into steam of 2-10 bar at the lowest operational costs compared to others. Moreover generating steam is the best way to deliver useful energy to an industrial customer.

A pilot plant has been operated successfully by Qpinch at the premises of Indaver Antwerp. Operating the ICHP have shown unique heat lifts in transforming industrial waste heat from 100°C into steam of 150°C. The operating results of the 100kWth pilot plant were used as an input basis for Aspen process simulations. First physical properties were fitted, based on chemical composition analysis by UGent, to get the model of the installation close to the measured data and secondly the model was used to simulate the main engineering parameters to design future > 1MWth installations. The process simulation model which was engineered by PDC, proves that the overall efficiency of the new chemical heat pump system is comparable with industrial known Carnot efficiencies.

Keywords: Chemical heat pump, high temperature lift, industrial pilot plant, industrial heat transformer, heat recovery, waste heat recuperation

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[1] Corresponding author. Mob.: +32 486 090 842; Tel: +32 3369 9332
E-mail address: wouter.ducheyne@qpinch.com

1. General info on heat pump systems

Most commonly known heat pumps are based on mechanical compression. In this closed loop system, a gas is, after being compressed, condensed with a heat sink, followed by an expansion, typically done with an expansion valve, and finally evaporated with a heat source. This is a left turning Carnot cycle in which electricity is used to drive or pump the heat from low to high temperature. For some common known heat pumps as domestic tools or industrial heat pumps, the heat sources and heat sinks are depicted in the table below.

Table 1. Common heat pump applications

HP equipment (domestic / industrial)	Heat Source (°C)	Heat Sink (°C)	Temperature lift (°C)	Electrical consumption (%)	max. COP (Carnot)	Commercial COP[i]
Refrigerator	-20	25	45	25	6.7	4
Airco	15	30	15	20	20.2	4.5
Industrial feed water heating	60	85	25	25	14.3	3.8 -5.4
Greenhouse farming with HP [2]	18	62	44	29	7.6	3.5
Industrial chips dryer with HP[3]	40	75	35	18	6.3	5.5

2. Challenges for a sustainable industrial energy supply

The main challenge for industry is to reduce the greenhouse gas production, mainly CO_2 and NO_x in all existing and new assets. Taking into account that main gas emissions are produced by heat and power generation in most industrial processes, wasting heat should be avoided as much as possible and power consumption should be as low as possible. By transforming this waste heat into useful heat at low electrical consumption, heat pumps will deliver a major contribution to the creation of a sustainable low emission industry.

As can be seen in table 1, the electrical consumption of current commercial available heat pumps is high. Especially if compared to thermal compression heat pumps such as e.g. absorption heat transformers or physico-chemical heat transformers such as the Qpinch industrial heat transformer.

The process industry has an average on-stream time of 8000 hrs./y and green power, such as wind, is generated for 1800-2200 hrs./y [4]. In order to create a sustainable solution for future industrial energy generation, the gap with green power generation should be kept as small as possible or the industrial electrical power consumption should be kept as low as possible. That's why we at Qpinch believe that the transforming process from industrial waste heat into useful process heat should always take place with the lowest possible electrical power consumption. Besides this ecological approach, we expect[ii] the industrial electricity cost will increase due to higher network complexity initiated by increasing fluctuations of green power supply.

The recuperation of waste heat by using a small fraction of electricity (stream 3 of figure 1) compared to the useful output heat (stream 2 of figure 1), will be part of the solution to decrease the environmental impact of industry at economical attractive conditions.

[2] Source: "Warmte en CO2, voor een groene toekomst", presentation given on 11 03 2016 at a "glastuinbouw symposium"
[3] Source Mc Cain foods 2012 –880 kW Fries dryer with a heat pump De Kleijn / GEA Grenco
[4] http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/windenergie-op-land/techniek/opbrengst

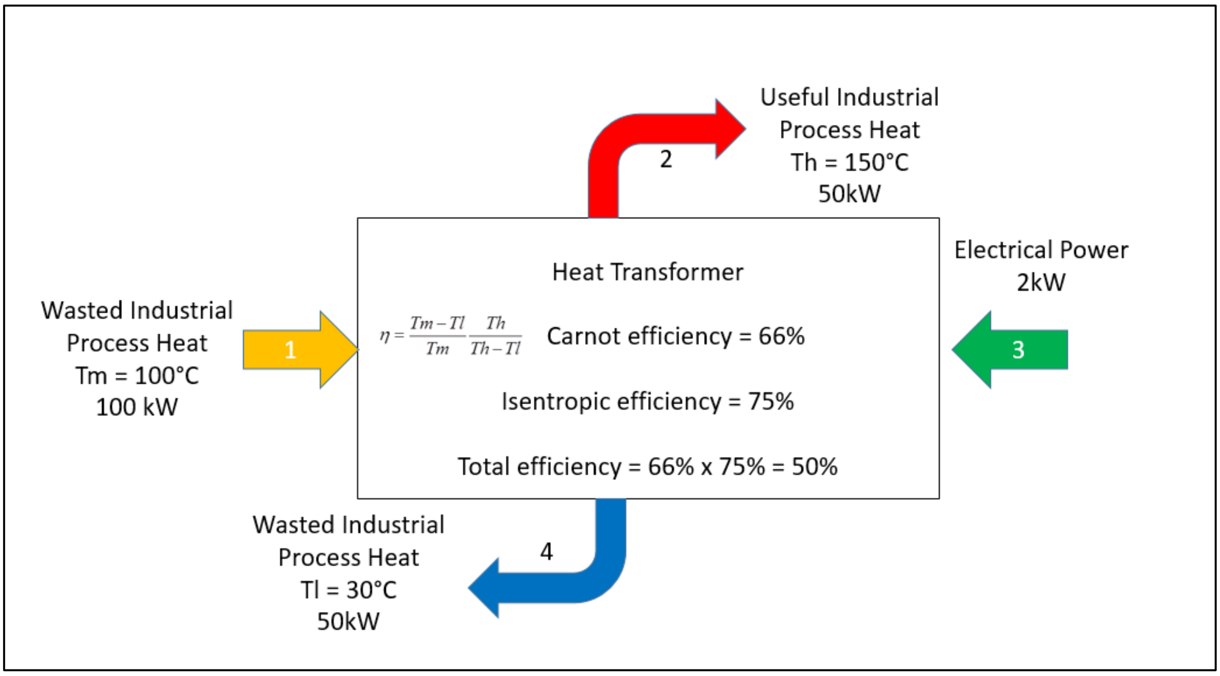

Figure 1 General energy flows of a heat transformer

In order to create an industrial economical and effective solution, following characteristics improve the economical applicability:

- High temperature lift between waste heat source 1 and useful process heat 2 (preferably 40-60°C)
- Low electrical consumption (preferably < 5%)
- Components without crystallization during usage in industrial assets
- No formation of side components in order to have a long lifetime of the working medium without intermediate replacements
- Capex should not generate paybacks over 5 years

3. Pilot plant integrated in industrial assets for upgrading waste heat above 75°C

Based on novel findings in collaboration with prof.dr.ir.Christian Stevens from Ghent University regarding the use of inorganic oxoacids and it salts and water, a first heat transformer prototype was tested. This system proved that heat from 75-150°C can be pumped up to 150-241°C[iii] by using a physico-chemical process with liquid phosphates and water. In a first step the water is removed by evaporation with waste heat before being condensed with ambient air or cooling water. By removing the water and heating up the phosphoric acid and its salts with the waste heat, an endothermic polymerization takes place (flow 1 of figure 2). The polymerized – oligomerized – product (flow 3 of figure 2) is brought to another step in which the water is added, after being condensed by cooling with a heat sink (flow 2 of figure 2) and evaporated with a waste heat source (flow 4 of figure 2). The condensation of water in the liquid acid and its salts generates a strong exothermal hydrolysis reaction resulting in a big temperature increase of the depolymerized working medium. The temperature increase (flow 5 of figure 2), is relatively large because the condensation energy of water in combination with the hydrolyzation energy is, depending on the polymerization degree, relatively high (estimated at 2500 kJ/kg) in comparison with the heat capacity of the liquid phosphoric acid medium (about 1.6 kJ/kgK). After the hydrolyzation and condensation, the acids and it salts and water mixture are recycled back to the first endothermic reactor (flow 6 of figure 2).

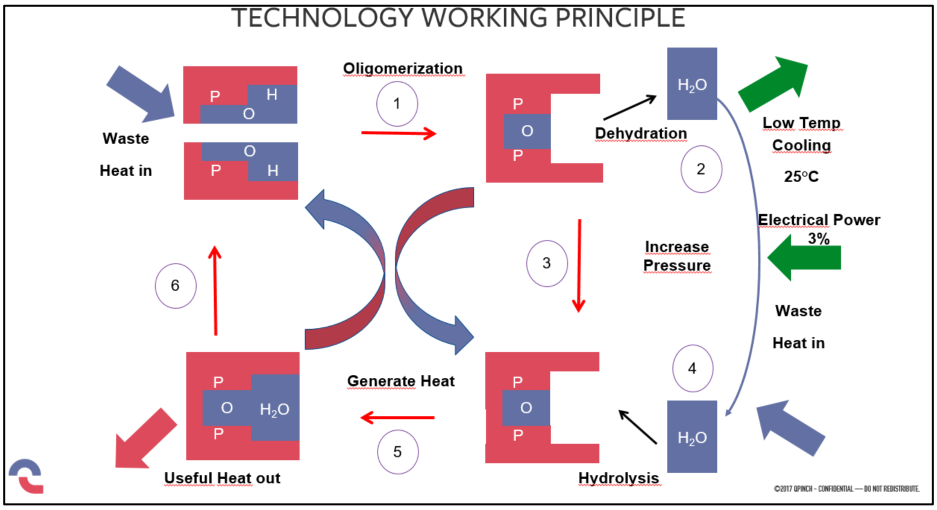

Figure 2 Working principle of industrial chemical heat pump

In 2015-2016 the first industrial 50 kW installation was installed and operated in an industrial environment at the premises of Indaver Antwerp. In total the plant ran for more than 2500 hours in runs of 30-40 days without stopping. After each run, the installation settings were changed to simulate different modes of operation, i.e. generating steam or heating up water.

Results of the 50 kW output (stream S2) ICHT are, as depicted in figure 2:

- Temperature lifts up to 57°C were measured
- Electrical power consumption[iv] (S3) was 7.5% of the useful heat output (S2)
- Commercial COP on average 13.8
- No fouling or formation of side products was encountered
- Sustainable materials for the containments
- Efficiency measurements of 40-50% were witnessed by VITO[v]

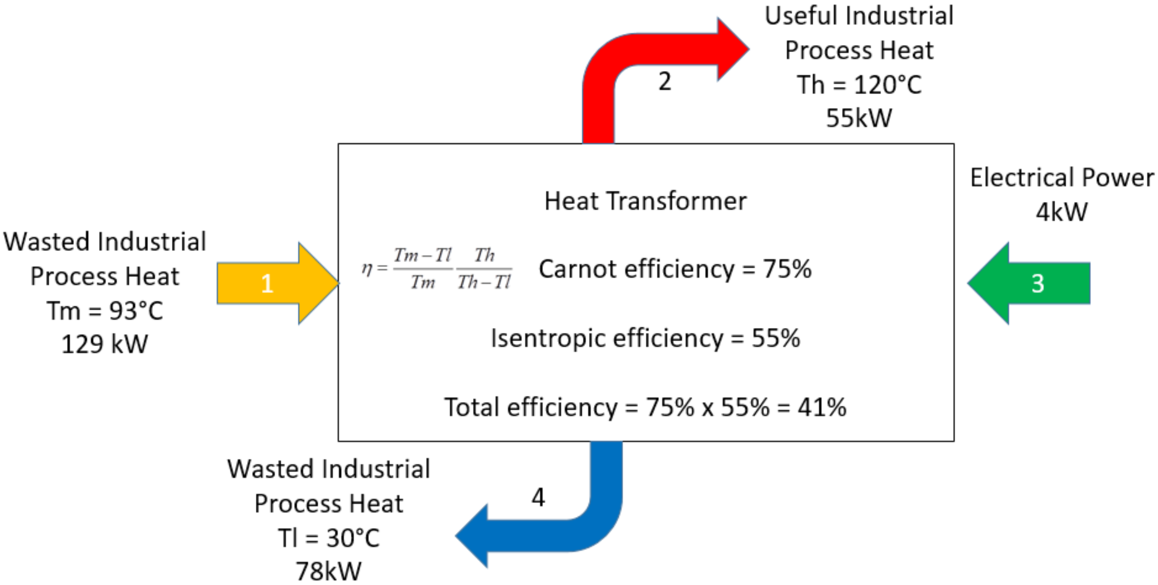

Figure 2. Average values of September 2016 tests with the pilot installation at Indaver Antwerp

Figure 3 Picture of Indaver Pilot Plant – Qpinch

Figure 4 Working @ Qpinch 50 kW output heat trafo at Indaver Antwerp, Belgium 2016

4. Discussion

In a first stage, a 5 kW demo plant has proven that the Qpinch technology is capable of transforming waste heat of 75-125°C into useful process heat of 120-200°C. In a later stage of the technology development path, a 50 kW pilot plant (100 kW input, 50 kW output as can be seen in figure 3 above) showed that this heat transformer, once

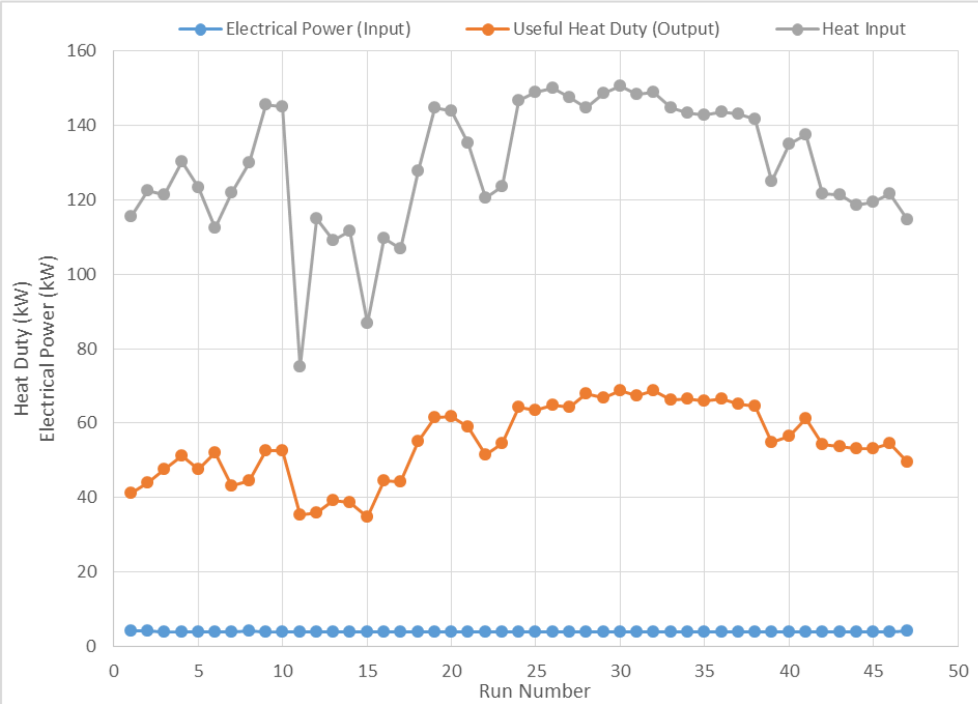

Figure 3. Overview of electrical input and in- and output heat duty

fully integrated in a real industrial environment, is capable to transform waste heat into steam with only a little electricity consumption of about 4 kW (see figure 3).

However, the scale of the installation was rather small, giving raise to relatively large heat losses (5-10% of the heat input), the efficiency appeared to be acceptable. It is expected that the efficiency for next MW installations will also be between 40-50%, depending on the temperature of the available waste heat and the desired steam output temperature.

The measured isentropic efficiencies[vi] vary (Isentropic efficiency = Actual efficiency / Carnot efficiency of heat transformer), depending on the desired temperature lift, between 39-68% with an average value of 60%.

By increasing the surface of the economizer for commercial installations, i.e. heat recuperator between the cold and the hot reactors, the isentropic and thus overall efficiency can be increased with up to 10% accordingly. The isentropic efficiency over time is shown in figure 4.

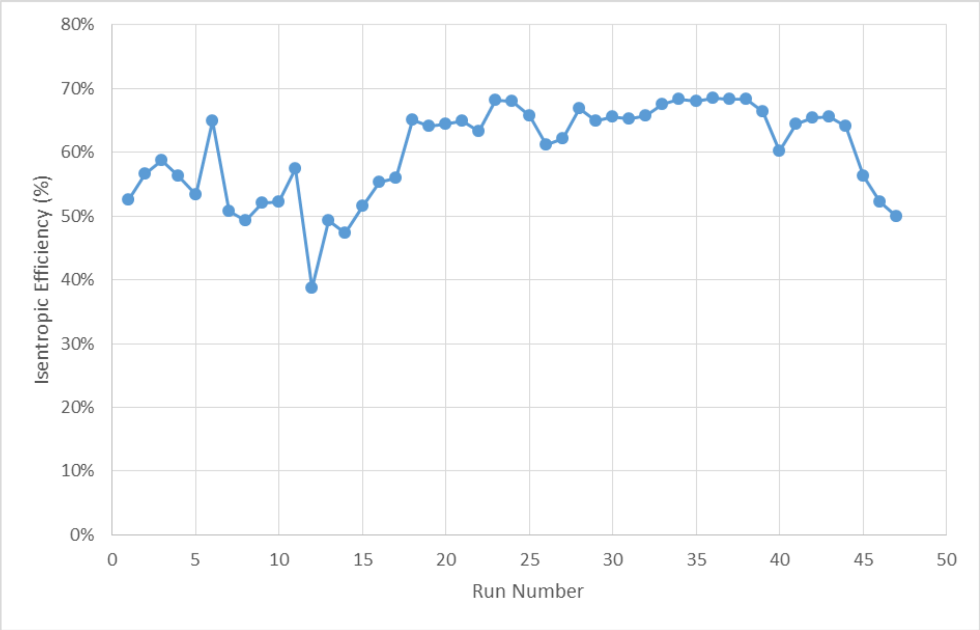

Figure 4. Isentropic efficiency over time

During the long runs, there was no efficiency decrease noticed due to e.g. the formation of side components in a sense that there is no correlation on performance during the run time of the pilot plant.

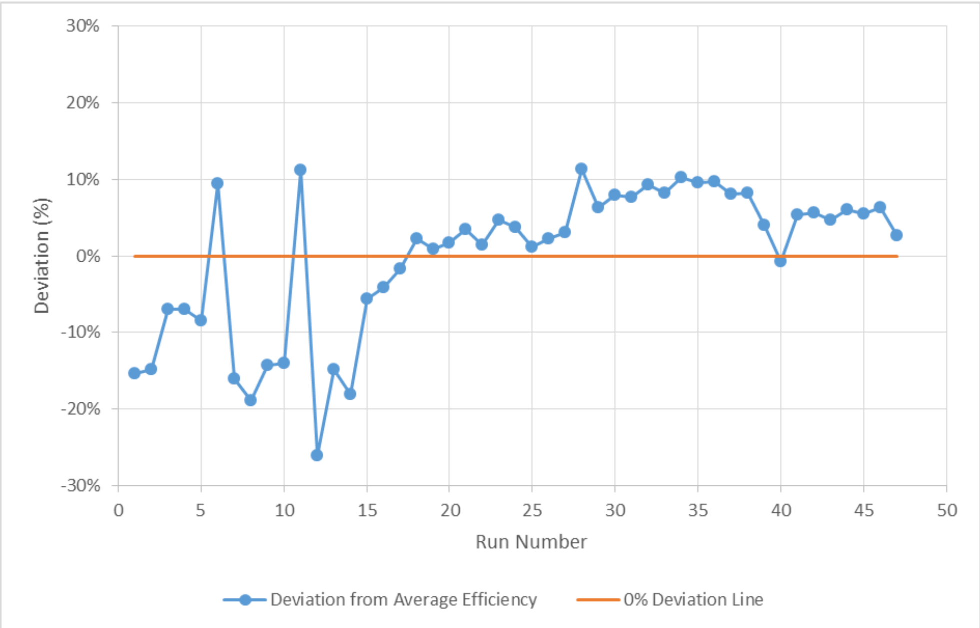

Figure 5. Deviation of the efficiency over time compared to the average efficiency

As can be seen in table 2, Qpinch estimates the operational – electrical-costs of the heat transformer are by far the lowest of all commercial applications. This is one of the mayor and unique selling points of the Qpinch technology

Table 2 Common heat pump applications and Qpinch ICHT set out versus operational Energy costs

HP equipment (domestic / industrial)	**Heat Source (°C)**	**Heat Sink (°C)**	**Temperature lift (°C)**	**Operational costs[5] based on electrical consumption €/y/MW installed[6]**
Refrigerator	-20	25	45	**150.000**
Airco	15	30	15	**120.000**
Industrial feed water heating	60	85	25	**150.000**
Greenhouse farming with HP	18	62	44	**174.000**
Industrial chips dryer with HP	40	75	35	**108.000**
New Qpinch ICHT	93	120	27	**45.000**

5. Further developments

PDC[vii] collaborated with Qpinch to develop a process simulation model of the new ICHT which is fitted on the experimental data that are retrieved during the tests with the pilot installation at Indaver Antwerp. First physical properties were fitted, based on chemical composition analysis by UGent, to get the model of the installation close to the measured data and secondly the model was used to simulate the main engineering parameters to design future installations.

The next step in the development of the Qpinch chemical heat pump will be a 1 MW installation which is expected to be operational in 2017.

Recently Qpinch teamed up with PDC in the European project SpotView. The objective of this SpotView project is to demonstrate the sustainable use of existing as well as novel technologies and processes in integrated water and waste water processing schemes for three major European industrials sectors, i.e. the Dairy, Pulp and Paper and the Steel Industry. The Qpinch ICHT is one of the selected novel technologies for demonstration.

The SpotView project, which started on 03/10/2016 and has a duration of 42 months, received funding from the European Union’s Horizon 2020 research and innovation program under Grant Agreement No. 723577. The project is also supported by the SPIRE PPP, via the SPIRE-01-2016 call: "Systematic approaches for resource-efficient water management systems in process industries".

6. Conclusion

Qpinch developed a new process to transform waste heat in the range of 75-125°C to useful heat of 120°C – 200°C. A 100 kW pilot plant ran stable for more than 2500 hours. The plant has been witnessed by VITO, stating that the efficiency was between 40% and 50%. The industrial chemical heat pump performed better compared to classical vapor compression heat pumps: the average temperature lift of inorganic oxoacids and its salts and water was 27°C, with peaks up to 57°C, depending on the mode of operation. This enables the ICHP to transform the waste heat into steam of 2-10 bar at the lowest operational costs compared to others. Moreover, generating steam is the best way to deliver useful energy to an industrial customer. The measured average rate of useful heat output and electrical input is 13.8. Qpinch expects the commercial COP of industrial MW installations will be up to 30.

The solution is applicable throughout all major industries that use industrial heat, including food and feed, chemical industry, paper and pulp, cement and power plants. It offers exceptional temperature lifts and unique payback times.

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[5] Operational costs exclusive the maintenance costs. Maintenance costs are typically 2-4% of CAPEX
[6] 75€/MWh & 8000hrs/y

7. References

- Patent reference: WO2012101110 (A1) — 2012-08-02
- http://www.duurzamehavenvanantwerpen.be/sites/default/files/Sustainability%20Award%202016_NDL_DEF.pdf
- https://en.wikipedia.org/wiki/Adenosine_triphosphate
- http://www.cathyberx.be/content/dam/cathy-berx/openingsrede/REDE_2016_Antwerpen_Omarm_de_warmte!_HRN__FINAL.pdf

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[i] COP is here defined commercially as the useful heat output divided by the electrical power input
[ii] The US EIA (Energy Information Administration) forecasts a price increase of 20% in Annual Energy Outlook for the US
[iii] Tests performed in 2012-2013 in an IWT project together with UGent, UA, Qpinch and ECN
[iv] Electricity is the internal electricity of the ICHT. The cooling fans and pumps were not incorporated in this value as they are supposed to be present in existing systems before the ICHT is installed to cool away the waste heat or to pump up the boiler feed water.
[v] Flemish Institute for Technological Research performed a witnessing which was not published.
[vi] Isentropic efficiency = Actual efficiency / Carnot efficiency of heat transformer
[vii] Process Design Center (PDC) is a leading consultant for conceptual process design as well as energy & resource efficiency improvement in the process industry

Adenosine triphosphate (ATP) is a nucleotide also called as nucleoside triphosphate is a small molecule used in cells as a coenzyme. It is often referred to as the "molecular unit of currency" of intracellular energy transfer.[1]

ATP transports chemical energy within cells for metabolism. Most cellular functions need energy in order to be carried out: synthesis of proteins, synthesis of membranes, movement of the cell, cellular division, transport of various solutes etc. The ATP is the molecule that carries energy to the place where the energy is needed. When ATP breaks into ADP (Adenosine diphosphate) and Pi (phosphate), the breakdown of the last covalent link of phosphate (a simple -PO4) liberates energy that is used in reactions where it is needed.

It is one of the end products of photophosphorylation, aerobic respiration, and fermentation, and is used by enzymes and structural proteins in many cellular processes, including biosynthetic reactions, motility, and cell division.[2] One molecule of ATP contains adenine, ribose, and three phosphate groups, and it is produced by a wide variety of enzymes, including ATP synthase, from adenosine diphosphate (ADP) or adenosine monophosphate (AMP) and various phosphate group donors. Substrate-level phosphorylation, oxidative phosphorylation in cellular respiration, and photophosphorylation in photosynthesis are three major mechanisms of ATP biosynthesis.

Metabolic processes that use ATP as an energy source convert it back into its precursors. ATP is therefore continuously recycled in organisms: the human body, which on average contains only 250 grams (8.8 oz) of ATP,[3] turns over its own body weight equivalent in ATP each day.[4]

ATP is used as a substrate in signal transduction pathways by kinases that phosphorylate proteins and lipids. It is also used by adenylate cyclase, which uses ATP to produce the second messenger molecule cyclic AMP. The ratio between ATP and AMP is used as a way for a cell to sense how much energy is available and control the metabolic pathways that produce and consume ATP.[5] Apart from its roles in signaling and energy metabolism, ATP is also incorporated into nucleic acids by polymerases in the process of transcription. ATP is the neurotransmitter believed to signal the sense of taste.[6]

The structure of this molecule consists of a purine base (adenine) attached by the 9′ nitrogen atom to the 1′ carbon atom of a pentose sugar (ribose). Three phosphate groups are attached at the 5′ carbon atom of the pentose sugar. It is the addition and removal of these phosphate groups that inter-convert ATP, ADP and AMP. When ATP is used in DNA synthesis, the ribose sugar is first converted to deoxyribose by ribonucleotide reductase.

ATP was discovered in 1929 by Karl Lohmann,[7] and independently by Cyrus Fiske and Yellapragada Subbarow of Harvard Medical School,[8] but its correct structure was not determined until some years later.[citation needed] It was proposed to be the intermediary molecule between energy-yielding and energy-requiring reactions in cells by Fritz Albert Lipmann in 1941.[9] It was first artificially synthesized by Alexander Todd in 1948.[10]