

**ЕНЕРГЕТИКА ТА ЕНЕРГОЗБЕРЕЖЕННЯ**

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**Energy efficiency projects deployment for Ukrainian industry. Efficiency assessment method for energy exchange and the ratio of temperature change in heat exchangers***O. Yakovleva*<sup>1✉</sup>, *O. Ostapenko*<sup>2</sup>, *V. Trandafilov*<sup>3</sup><sup>1,2,3</sup>Odessa National Academy of Food Technologies, 1/3 Dvoryanskaya str., Odessa, 65082, Ukraine✉ e-mail: <sup>1</sup>osarja@gmail.comORCID: <sup>1</sup><https://orcid.org/0000-0003-4785-9069>; <sup>2</sup><https://orcid.org/0000-0003-0990-7883>;<sup>3</sup><https://orcid.org/0000-0001-9905-9958>

*Energy efficiency projects deployment for Ukraine is one of the challenging task today. Ukrainian industry faces very complex environment for project development as well as its deployment within organization nowadays. UA Policy struggle to keep place on the European market to have possibility not only be a part of global policy but to go forward and to bring benefits for macro and micro economy. Fresh breath by integration energy systems within project management into business model of organization let to move closer to hold under control energy efficiency projects realization and avoid financial risks. Environmental policy and energy policy play crucial role for Ukrainian transformation into European player. Presented proactive plan provides possibilities to deliver the intended economic and environmental benefits of the Ukrainian energy labelling and ecological design directives. These directives are in use or are under development process by increasing the rates of compliance with their energy efficiency requirements. To start from the energy efficiency development process investigation in order to have possibilities to make corrections on the stage of modeling and design can bring benefits and reduce costs for end users. To evaluate the efficiency of heat exchangers, there are over 40 different private integral energy efficiency criteria. Such a number makes the estimation of heat exchangers not always objective and sufficiently definite, which does not allow to algorithmize the task of determining the efficiency of heat exchangers. On the foundation of the system element representation for the heat exchange network, the concepts of energy potential and energy efficiency of energy exchange are proposed. The obtained equations allow us to determine the efficiency of energy exchange not only for an element of the heat exchange network, but also for a complex system as a whole with a minimum of information about the system.*

**Key words:** Energy Efficiency; Energy Efficiency Projects; Heat Exchanger; Heat Exchanger Networks; Effectiveness Criteria; Energy Policy

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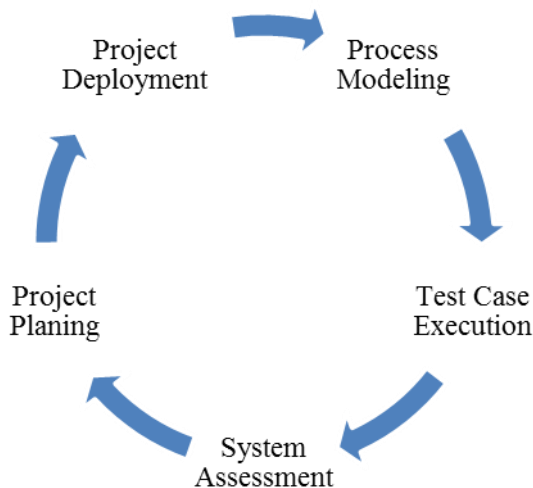
<http://creativecommons.org/licenses/by/4.0/>**1. Introduction**

One from energy efficiency (EE) criteria for energy efficiency projects (EEP) in the energy sector at a whole (here we look for energy systems as highest

hierarchy object which is intake any production system producing or transforming energy within any sector) and chemical sector in particular (as an application task represented) is direct CO<sub>2</sub> emissions reduction. It reached 1,25 Gt in 2017, which a 2% increase

from the 2016 year. In the sustainable development scenario, regardless of continued strong growth in demand, the chemical sector's emissions increase at a much more modest rate before peaking around 2025 and returning to today's level by 2030 [1]. In order to get on track, some efforts from government and industry are needed to be employed to address CO<sub>2</sub> emissions from chemical production. It contributes to the shift of Ukrainian regions towards low-carbon society by enhancing the capacities of municipalities and regional representatives to shape integrated energy strategies and plans which goes apart Energy Strategy of Ukraine until 2035 [2]. Sustainable development integration into energy systems helps address the global challenges Ukraine face, including those related to climate change, environmental degradation.

A more than 30% increase in energy demand for primary chemicals production nowadays. In the short to medium term perspective, it can be achieved primarily by raising energy efficiency and to deploy EEP for each step within incremental development.



**Figure 1** – Incremental development process for EEP decision making in chemical industry [3].

To create required balance for EEP development in between energy efficiency improving and environmental impact reducing for holding quality of EEP on high level is a required step to attract investment in chemical sector for EEP from project development process to its deployment.

In some cases, when assessing the energy efficiency for chemical system production, it is essential to define the efficiency of a particular heat exchanger (HE). In chemical industry, the concept of energy efficiency of a HE is not discussed for engineers. Can this fact be assessed as a mistake? No. Efficiency in this case is formally the ratio between energy input

and energy output. In practical use, it does not consider. The efficiency for HE, despite small heat loss, less than 1%, is the heat transfer coefficient in the HE and it can be accepted a 100% rating. There is opportunity to improve the heat transfer performance, but by very small amounts. Engineers at the production companies are not worried, when they do heat balance, they assume the thermal efficiency is 100% and say the “hot side is equal to the cold side” [4]. Sometimes specialists arbitrarily use a heat transfer coefficient of 0.95 is used, without good understanding of theoretical basis for this case.

What way can we bring with to assess the performance of any heat exchanger? The performance of the HE can be appraised in several ways: effectiveness, UA analysis, fouling estimation, comparison of the HE energy performance with design. HE performance can be varied. In this case, how should HE performance be correlated, to operating cost or energy savings? It is the crucial issue cause of HE a process shutdown determination. Is it required for HE cleaning? Can HE operation be continued in accordance with planned shutdown for HE maintenance? Decision making for this comes up with operating capacity as well as bottlenecks. It is recommended to categorize HEs which is ineffectively operating. Next step is to quantify the opportunities for the energy savings and cost savings. It is valid for HEs which are operating at proper design levels.

## 2. Analysis of existing Heat Transfer Effectiveness Evaluation Criteria

In HEs, the amount of energy rejected by hot utility is always equal to the amount of energy received by the cold utility. In this respect, when determining the integral characteristic of HEs, experts face a problem arisen related to the method for determining the maximum possible amount of energy which is transferred during the heat exchange process and hereinafter referred to as the HE energy potential.

Formally effectiveness,  $\varepsilon$ , is defined as “normalizing factor” the ratio of the actual heat transfer rate for a HE to the maximum possible heat transfer rate, specifically

$$\varepsilon = \frac{Q}{Q_{\max}}, \quad (1)$$

where  $Q$  – actual heat transfer;  $Q_{\max}$  – maximum possible heat transfer, that can be transferred in an ideal

countercurrent heat exchanger with an infinitely large heat exchange surface.

In [5], the authors introduce the concept of HE  $\varepsilon$  for Co-Current flow, cold fluid minimal which is determined by:

$$\varepsilon = \frac{W_{hot} \cdot (t_{hot1} - t_{hot2})}{W_{min} \cdot (t_{hot1} - t_{cold2})} = \frac{W_{cold} \cdot (t_{cold2} - t_{cold1})}{W_{min} \cdot (t_{hot1} - t_{cold1})}, \quad (2)$$

where  $t_{hot1}, t_{hot2}$  – temperature of hot fluid;

$t_{cold1}, t_{cold2}$  – temperature of cold fluid;

$W_{hot}$  – water equivalent for hot fluid;

$W_{cold}$  – water equivalent for cold fluid;

$W_{min}$  – minimal amount from  $W_{hot}$  and  $W_{cold}$ .

HE energy potential is in the denominator of the eq. (2).

It should be noted that in a number of other works the  $Q_{max}$  authors determine differently. In [6] when determining the heat transfer efficiency, the equation:

$$\varepsilon = \frac{\delta t}{\Delta t}, \quad (3)$$

where  $\delta t$  – variation in temperature, hot fluid;

$\Delta t$  – temperature difference, HE inlet streams.

In [7], the authors introduce the concept of heat exchanger effectiveness, which is determined by the equation:

$$\varepsilon = \frac{(t_{li} - t_{le})_i}{(t_{li} - t_{le})}. \quad (4)$$

The numerator of the eq. (4) contains the temperature difference between the inlet and outlet temperatures for one of the media where this difference is the largest. The denominator is the temperature difference between HE inlet streams and plays the role of a “normalizing factor”, which allows to limit the efficiency value in eq. (4).

The introduced ratio needs to be clarified if there is a temperature dependence of the heat capacity. For this, Hausen [8] proposed to use the values of the total enthalpy of flows to determine the efficiency:

$$\varepsilon = \frac{I'_1 - I''_1}{I'_1 - I'_2}, \quad (5)$$

where in the numerator is the difference in the total enthalpies of the heating stream, and in the denomina-

tor is the difference in the total enthalpies of the HE inlet streams.

However, as Jacob notes, the eq. (5) does not go over into eq. (1) in a continuous way if the thermo-physical properties of the HE streams depend substantially on temperature.

Sometimes, in order to get out of this situation, when determining the effectiveness, ratio that include specific design and technological data of the HE is used. For example, Altenkirch in [9], using the temperature difference of the inlet streams as a “normalizing factor”, introduces a correction factor in the form of the multiplication for heat transfer coefficient  $k$  and the heat transfer surface  $F$ . But this leads to the fact that the opportunity of formalizing such a concept of heat transfer efficiency disappears. The value ( $kF$ ) must be determined for each specific case.

Thus, the existing definitions of the integral characteristics for HEs significantly differ fundamental way energy potential or the normalizing factor choice, which does not allow problem algorithmizing for the HE efficiency determining.

## 2. The concepts of energy potential, energy exchange efficiency, and temperature change efficiency in a heat exchange network element

Consider an element of a heat exchange network in which energy is exchanged between two flows (Fig. 2).

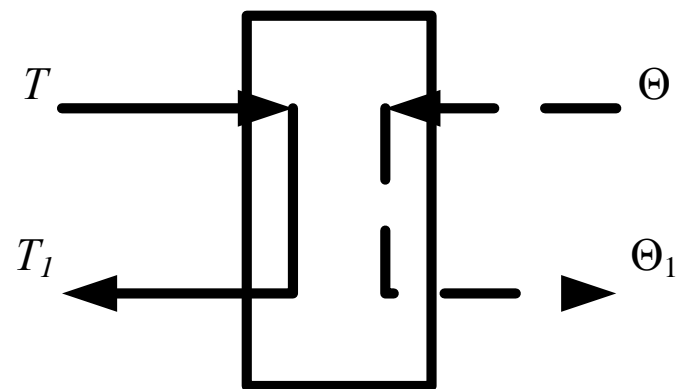


Figure 2 – Heat Exchanger Network element

Having identified the energy stream with the concept of total enthalpy, it is easy to write the energy balance for an element in the form:

$$H - H_1 = I_1 - I \Rightarrow CP_{heating} (T_1 - T) = CP_{heated} (\Theta - \Theta_1), \quad (6)$$

where  $H$  – total enthalpy for stream with higher ener-

gy measure;  $I$  – total enthalpy for stream with lower energy measure.

Denote  $T$ ,  $\Theta$  as energy measures, a  $CP_{heating}$ ,  $CP_{heated}$  – as consumable heat capacities of the heating and heated streams, respectively.

The index “one” defines the values of the total enthalpy and temperatures at the outlet of the element, the values without indices refer to the inlet streams. Consider the  $Q, T$ -diagram of a Heat Exchange Network element (Fig. 3).

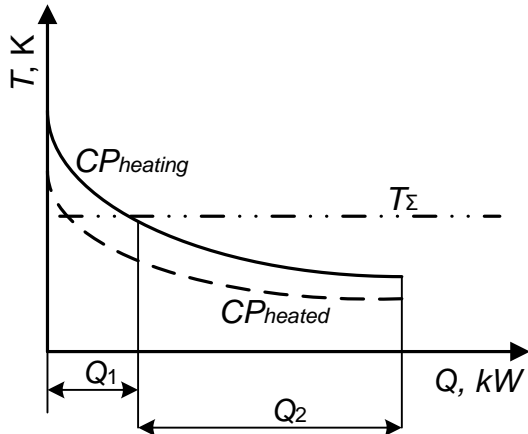


Figure 3 –  $Q, T$ -diagram of a heat exchange network element

If measures and expendable heat capacities of streams are set at the system element input, then the average enthalpy temperature  $T_{\Sigma}$  for the system element can be determined:

$$T_{\Sigma} = \Theta_{\Sigma} = \frac{T \cdot CP_{heating} + \Theta \cdot CP_{heated}}{CP_{heating} + CP_{heated}}. \quad (7)$$

The amount of energy that a stream rejects with a higher energy potential until the temperature thermodynamic equilibrium is reached is determined:

$$Q_1 = T \cdot CP_{heating} - \frac{T \cdot CP_{heating} + \Theta \cdot CP_{heated}}{CP_{heating} + CP_{heated}} \cdot CP_{heating}. \quad (8)$$

The amount of energy that a stream with a lower energy potential takes until the temperature thermodynamic equilibrium is determined:

$$Q_2 = \frac{T \cdot CP_{heating} + \Theta \cdot CP_{heated}}{CP_{heating} + CP_{heated}} \cdot CP_{heated} - \Theta \cdot CP_{heated}. \quad (9)$$

The maximum possible amount of energy that

streams can exchange:

$$\begin{aligned} \Delta\Phi &= Q_1 + Q_2 = 2 \cdot CP_{heating} \cdot CP_{heated} \cdot \frac{T - \Theta}{CP_{heating} + CP_{heated}} = \\ &= 2 \cdot CP_{heating} \cdot \frac{1}{1 + \alpha} (T - \Theta), \end{aligned} \quad (10)$$

where  $\alpha = (CP_{heating} \cdot CP_{heated})$ .

$\Delta\Phi$  is considered as the limiting energy potential for an system element. The ratio of the actually transferred amount of energy  $Q$  to the energy potential is defined:

$$\eta_{\Sigma} = \frac{Q}{\Delta\Phi} = \frac{CP_{heating} + CP_{heated}}{2CP_{heated}} \cdot \frac{T - T_1}{T - \Theta} = \frac{1 + \alpha}{2} \cdot \varphi, \quad (11)$$

where  $\varphi = (T - T_1)/(T - \Theta)$ .

The ratio of the actually transferred energy to the energy potential will be considered as the energy exchange efficiency  $\eta_{\Sigma}$ , and the ratio of the temperature change in the system element to the temperature difference at the inlet will be considered as the efficiency of the temperature change  $\varphi$ .

### 3. The Industrial Decarbonization. EEP in the Chemical Sector Action Plan proposal for Ukraine adoption

The chemicals industrial decarbonization and global energy efficiency project deployment showed that decarbonization is attainable for EU as well as for Ukraine. On global market chemical companies face substantial barriers [10]. Among them:

- Competition for resources, funding internally;
- Prices for energy and costs for policy;
- Rigorous return on investment (ROI) requirements to clarify system assessment process;
- Ambiguity in policy and regulation states;
- Access to capital and funding attracted for development;
- Commercialization of new and unproven technology without proper assessment for EEP deployment;
- Unacceptable cost of research, development and demonstration of innovative technology;
- Extended lifetime of major equipment.

The ways that investigated how the chemical sector could possibly decarbonize, to 2050, involved the deployment of opportunities comprising:

- Incremental improvements to existing technology during EEP development and deployment;

– Upgrades to deployment best available technology;  
 – The submission of substantial process changes consuming ‘disruptive’ technologies that offer the potential to become commercially viable in the medium term. (biomass/bioenergy and industrial carbon capture and storage/use to improve RES rating pointed out by Energy Strategy for 2035 in Ukraine).

In order to overcome barriers a set of activities should be applied which can be adoptable for Ukraine:

- To attract carbon efficient investment – smaller EEP targeted at improving existing assets using technologies that are now accessible.
- To apply activities which are intended at understanding and improving the techno-economics of the opportunities and finding ways to encourage EEP implementation.
- To perform strategic replacement of assets – while companies preferably require chemical industrial EE investments to attain a short payback (< 2 years) period.
- To perform new assets replacement or development for companies which make strategic business decisions and can accept a longer payback period.
- To care activities targeted at representing innovative tools, techniques, systems and technologies on actual working plants or assets, can support less mature solutions.
- To apply joint government – industry demo EEP.
- To use greater breakthrough technology or processes for development and deployment of EEP which involve public and private sector consortium for attracting investment and project delivery.

#### 4. Conclusions

1. The existing definitions of the integral characteristics of heat exchangers significantly differ from each other by the choice of the energy potential or the “normalizing factor”, which does not allow to algorithmize the problem of determining the efficiency of heat exchangers.

2. Based on the representation of the heat exchange network element, the concepts of energy potential, energy exchange efficiency, and temperature change efficiency for the network element are introduced.

3. The proposed concept allows:

- build a mathematical model of a complex heat exchange network and determine the effectiveness of energy exchange for the system as a whole with a minimum of information about the system;
- to perceive information in the form of algorithms acceptable for software development, in order to automate the construction of a system of equations.

4. Using Incremental development process for energy efficiency projects from start to project deployment let companies to clear project assessment for system measurement.

5. Understanding industrial problems by way of EEP deployment together with government representatives let politicians to create effective policies which can put rigorous requirements for attracting foreign investment to Energy Efficiency development in Ukraine.

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# Розгортання проектів з енергоефективності для української промисловості. Метод оцінки ефективності енергообміну та відношення зміни температури в теплообмінниках

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*Розгортання проектів з енергоефективності для України сьогодні є одним із складних завдань. Сьогодні українська промисловість стикається з дуже складним середовищем як для розробки проектів, так і для їх розгортання всередині організації. Українська політика веде боротьбу, щоб утримати місце на європейському ринку, щоб мати можливість не лише бути частиною глобальної політики, але йти вперед та приносити користь макро- та мікроекономіці. Свіжим диханням в рамках управління проектами є шлях інтеграції енергетичних систем в бізнес-модель організації, що дозволяє наблизитися та утримати під контролем реалізацію проектів з енергоефективності та уникнути фінансових ризиків. Екологічна та енергетична політика відіграють вирішальну роль для перетворення України на європейського гравця. Представлений ініціативний план надає можливість забезпечити заплановані економічні та екологічні вигоди від українських директив щодо енергетичного маркування та екологічного дизайну. Ці директиви використовуються або знаходяться в процесі розробки за рахунок підвищення рівня відповідності їх вимогам щодо енергоефективності. Початок дослідження процесу розвитку енергоефективності, щоб мати можливість вносити виправлення на етапі моделювання та проектування, може принести користь та зменшити витрати для кінцевих споживачів. Для оцінки ефективності теплообмінників існує понад 40 різних приватних інтегральних критеріїв енергоефективності. Така кількість робить оцінку теплообмінників не завжди об'єктивною та достатньо визначеною, що не дозволяє алгоритмізувати завдання визначення ефективності теплообмінників. На основі представлення елемента системи для теплообмінної сітки запропоновано концепції енергетичного потенціалу та енергоефективності енергообміну. Отримані рівняння дозволяють визначити ефективність енергообміну не тільки для елемента теплообмінної сітки, але і для складної системи в цілому з мінімумом інформації про систему.*

**Ключові слова:** Енергоефективність; Проекти енергоефективності; Теплообмінник; Сітки теплообмінника; Критерії ефективності; Енергетична політика

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