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ORIGINAL RESEARCH ARTICLE

CyclePad-based modeling of simple heat exchangers: Educational case study in parallel and counterflow configurations

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ABSTRACT

This article explores the use of CyclePad software for modelling and analysing simple heat exchangers by focusing on its application in educational and preliminary design contexts. Heat exchangers are the essential devices for thermal energy transfer. Modelling heat exchanger quickly by using hand calculation is time consuming and sometimes also leads to errors. Therefore, CyclePad has been used to model heat exchanger which is having an intuitive drag-and-drop interface that can makes the configuration of parallel and counterflow arrangements quickly. The study involves two case studies: in one ait to air exchange takes place whereas in the second air to water (involving phase change) happens in both parallel as well as counter flow arrangements. Key performance metrics considered in the study are Log Mean Temperature Difference (LMTD), heat transfer rates, and mass flow rates, which are calculated and compared for different flow configurations. Results demonstrate that CyclePad provides accurate and reliable solutions which are supported well with theoretical methods, while offering a user-friendly platform for visualizing the thermodynamic processes. The findings highlight the value of CyclePad in engineering education by bridging the gap between theory and practical implementation.

Keywords: Heat exchanger; heat exchanger simulation; CyclePad; LMTD, process innovation

1. Introduction

Heat exchangers are necessary in various industrial applications as they serve as a critical device for transferring the thermal energy between two or more fluids [1,2]. These fluids are normally separated by a solid wall, which prevents their direct mixing while allowing efficient heat transfer. Usual types of heat exchangers includes shell-and-tube, plate-and-frame, and finned-tube exchangers, each designed for specific design requirements and applications [1]. Many researchers have carried out research work on Heat exchanger [2-5]. Heat exchangers can also be categorized based on their flow arrangement into mixed flow, recuperative, and regenerative types. This article aims on the recuperative type of heat exchanger where the cold and hot fluids are separated by a solid boundary. Among the various configurations of recuperative heat exchangers the parallel and counter flow arrangements are the most common [6].

In parallel flow case, both the fluids move in the same direction whereas, in a counter flow heat exchanger the motion of fluids is in the opposite directions. **Figure 1** shows the fluid motion in both parallel and counter flow configurations [4]. Additionally, it presents typical temperature profiles for the fluids which offers a clearer understanding of the heat transfer mechanisms for both the cases.

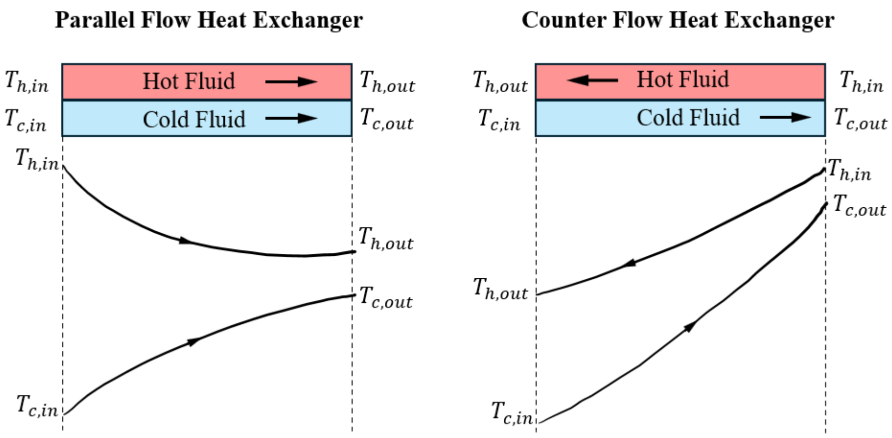


Figure 1. Flow patterns in parallel and counter flow heat exchangers and their respective temperature profiles

The rate of heat transfer ($\dot{Q}$) in a heat exchanger can be evaluated with the help of Eqn. 1 [1].

$$\dot{Q}=U\times A\times \Delta T_{LM} \tag{1}$$

Where, U, A, and Δ_{LM} are the overall heat transfer coefficient, area, and Log Mean Temperature difference (LMTD), respectively.

The LMTD relates the temperature difference between the two fluids at inlet and exit of heat exchanger and provides a logarithmic average. It is mathematically represented as [1]:

$$\Delta T_{LM}=\frac{\Delta T_1\text{-}\Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

Here, ΔT_1 and ΔT_2 shows the temperature difference between hot and cold fluid at the two ends. For parallel and counter flow the expression for these two are shown in **Table 1**.

Table 1. ΔT_1 and ΔT_2 for parallel and counter flow heat exchanger

	Parallel Flow	Counter Flow
$\boldsymbol{\Delta T_1}$	$T_{h,in}$-$T_{c,in}$	$T_{h,in}$-$T_{c,out}$
$\boldsymbol{\Delta T_2}$	$T_{h,out}$-$T_{c,out}$	$T_{h,out}$-$T_{c,in}$

2.CyclePad software

CyclePad is a powerful and user-friendly software tool designed for the simulation and analysis of thermodynamic systems. It is developed by professors at Northwestern University, is built entirely using Allegro CL and integrates the CogSketch understanding framework. CogSketch serves as an innovative tool for cognitive science research and educational purposes [5]. Allegro CL 11.0 is renowned for its efficiency in creating and deploying neuro-symbolic applications, bridging the gap between symbolic AI reasoning, large language models, and graph-based approaches. To enhance its graph-based functionality, Allegro Graph is included as a plugin [6]. This addition enables the storage and retrieval of both structured and unstructured data from Large Language Models (LLMs) and supports intelligent query handling and text retrieval through its built-in vector database. CogSketch, though primarily designed to improve sketch-based communication for engineering students, is currently optimized for modelling a subset of basic 2D mechanical systems [7]. It provides a comprehensive environment for building and analysing models of various components, including heat exchangers, pumps, turbines, and more [8,9]. Key features of CyclePad include:

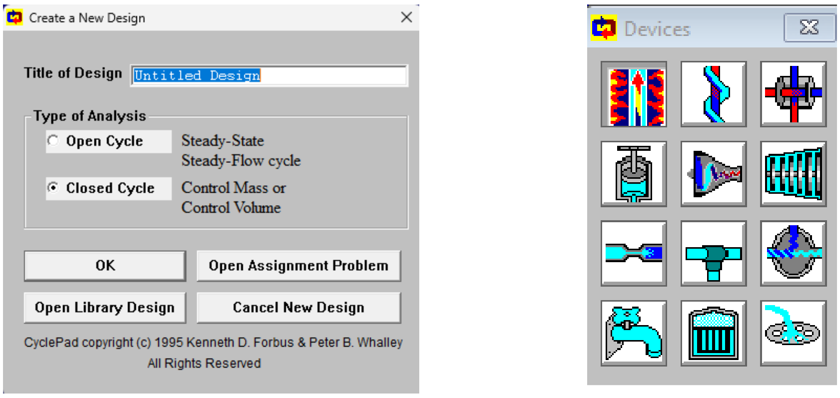
- CyclePad employs a drag-and-drop interface, making it easy to assemble system components and visualize the thermodynamic processes.
- The software offers a wide range of pre-defined components, allowing users to model complex systems with ease.
- CyclePad can do both steady-state and transient simulations thereby providing a deeper insight into the dynamic behaviour of thermal systems.
- The software facilitates data analysis along with data visualization which help the users to generate complete reports and presentations.

For detailed explanation on how the cycle pad works, modes in which it work, components it can handle, and model analysis one can refer to the article by Dumka et al. [10].

The originality of this article lies in its detailed study of using CyclePad software to model simple heat exchangers. While conventional methods for analysing heat exchangers rely on manual calculations or advanced simulation tools, the CyclePad offers a user-friendly approach that permits the students and researchers to visualize thermodynamic processes and build a deeper conceptual understanding. This study not only shows the modelling process in the CyclePad but also evaluates its accuracy and practicality compared to conventional methods. By focusing on the educational and analytical capabilities of CyclePad, this work bridges the gap between theoretical learning and software-based implementation. Therefore this tool is a valuable source for engineering education and early-stage design evaluations.

3. Modelling a heat exchanger in CyclePad

For modelling heat exchanger, the components used will be source, sink, and heat exchanger. In CyclePad, these components are present in the Open-Cycle setting. Once we select new design from the file menu, this setting will be seen. **Figure 1 (a)** shows this window whereas, **Figure 1 (b)** shows the components available in the Open-Cycle setting.



i.New design window ii.Devices in open cycle

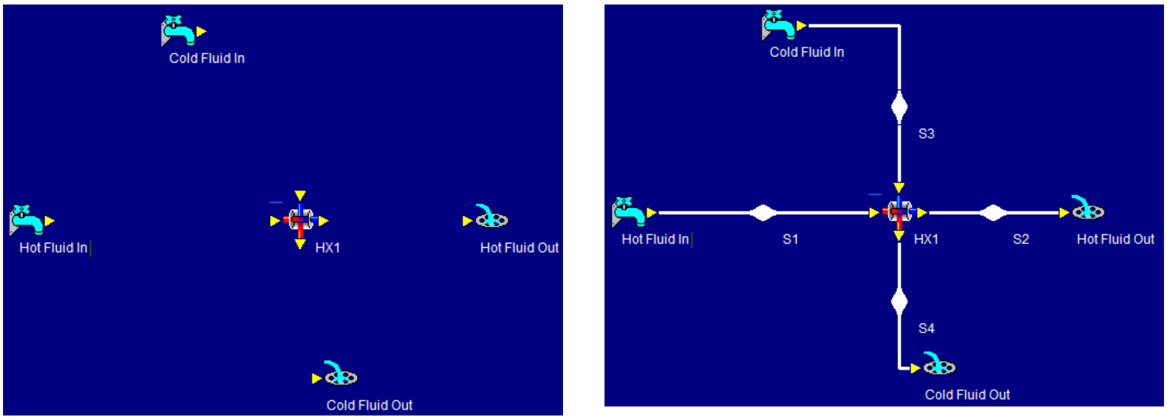
Figure 2. New design creation window along with devices window in open cycle setting

Among all the devices, **Table 2** shows the devices which will be used to model a heat exchanger.

Table 2. Devices and their symbol in CyclePad

S. No.	Name of device	Symbol of device in CyclePad
1	Source	
2	Sink	
3	Heat Exchanger	

Two source, two sinks and one heat exchanger are required to model a heat exchanger problem. Thus, the primary setting of the model in the *Build mode* is shown in **Figure 2 (a)** whereas, **Figure 2 (b)** shows the final model with the connections.



Arrangement of sources, sink and heat exchanger Connecting all the components

Figure 3. Arrangement and interconnections of the components in the build mode

Here one can see the *stuffs* which are marked from S1 to S4. These are places where one must supply the input and exit conditions of the fluids. Once this is done, the design page will automatically switch to the *Analyze* mode. Once in the *Analyze* mode, the models background changes and looks line as shown in **Figure 4**.

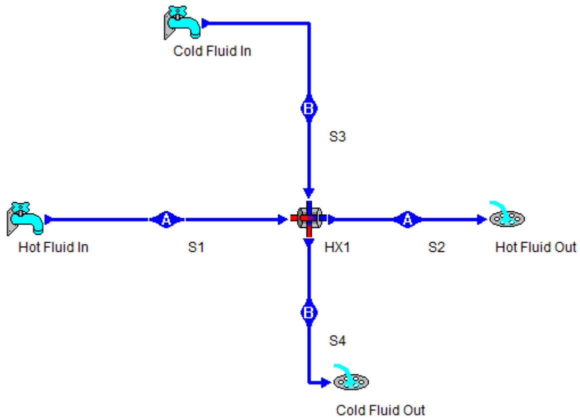
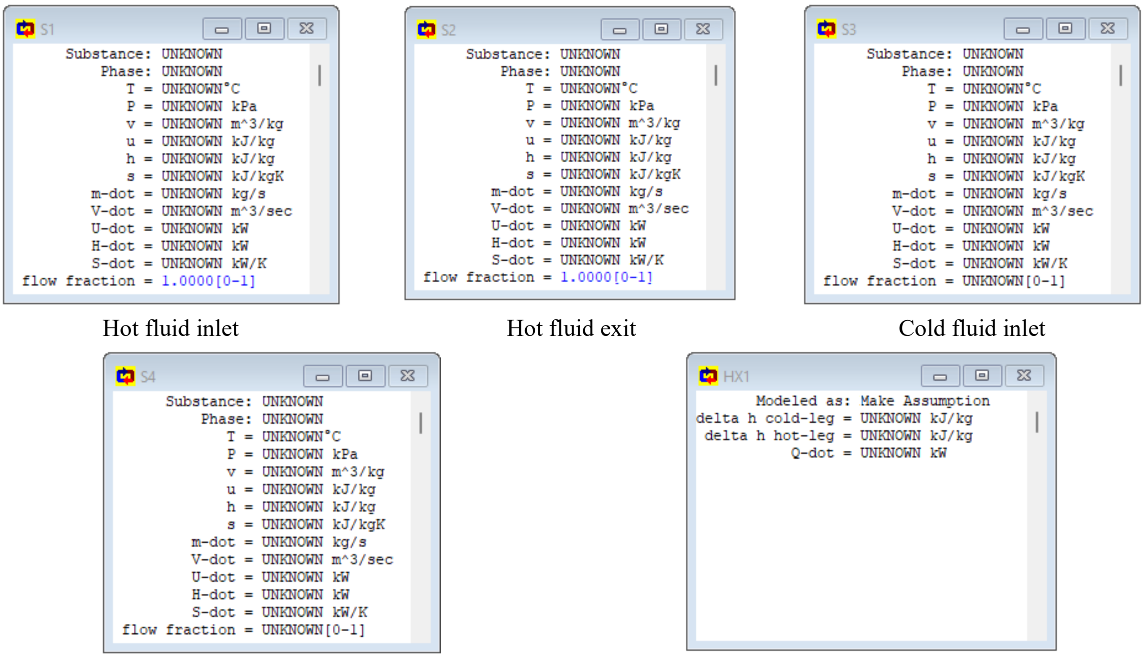


Figure 4. Model in the *Analyze* mode

Now, one has to supply the inlet/exit temperatures of the hot and cold fluid, mass flow rates (if known), the type of flow in the heat exchanger, and the type of heat exchanger (parallel or counter flow). These information's will be filled in the *meters* of all the stuffs components (Ref. **Figure 5**).



Hot fluid inlet — Hot fluid exit — Cold fluid inlet

Cold fluid exit — Heat Exchanger

Figure 5. *Meters* for different stuffs and components

Steps to be followed in modelling are:

- Select the hot fluid in s1and the cold fluid in s3 (i.e. air, hydrogen, water, etc.).
- Enter the inlet and exit temperature and pressure of hot fluid in s1 and s2 along with the mass flow rate.
- Repeat the above step for the cold fluid as well (usually mass flow is not known).
- The in the heat exchanger *meter*, enter the assumptions i.e. flow process in hot and cold side along with the type of heat exchanger i.e. counter flow (counter-current) or parallel flow (co-current).

4. Case studies

Case-1: A counterflow heat exchanger heats air at 100 kPa from a temperature of 25 to 700°C. The temperature of the heating fluid (Helium at 100 kPa) at the entry and exit are 1900 and 1300°C, respectively.

The task is evaluating the LMTD, flow of air for 1 kg/s flow of Helium, and heat transfer. Also, it must be checked that what will happen to the above-mentioned parameters if the heat exchanger is a parallel flow heat exchanger.

Solution:

The model build above (**Figure 4**) will be used.

First, setting meter for s1 to s4 as shown in the **Figure 6**.

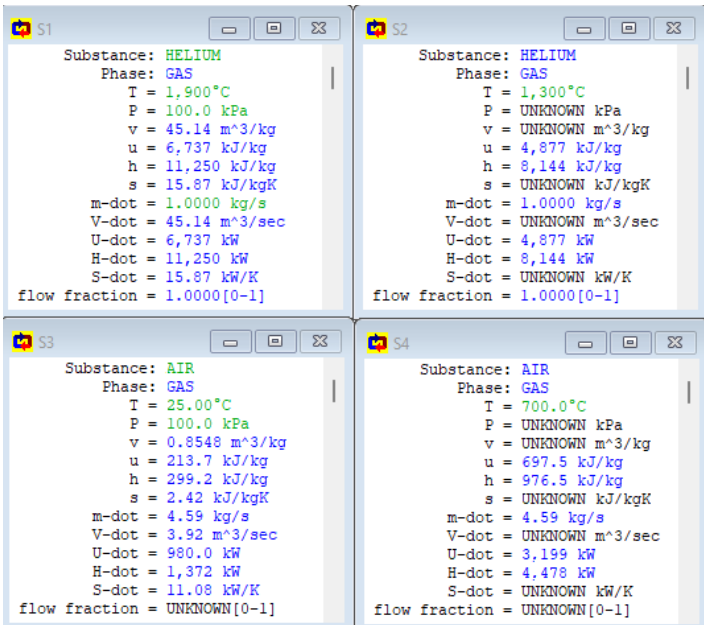
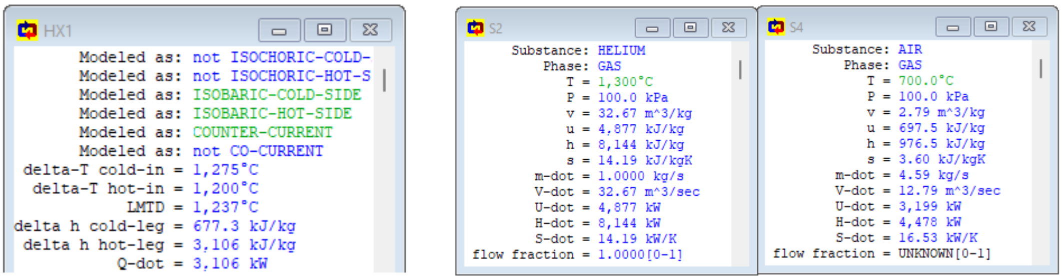


Figure 6. *Meters* for Case-1 (a)

(a) Now one can see that the pressure for the hot gas exit and cold gas exit is not known. This will show up once the *meter* for heat exchanger is set. Now for the heat exchanger set both the hot and cold fluid flow as isobaric and set HX-1 as counter-current (**Figure 7(a)**). Once this is done all the meters will get automatically solved (**Figure 7(b)**) and the desired parameters will be known (**Figure 7(a)**).

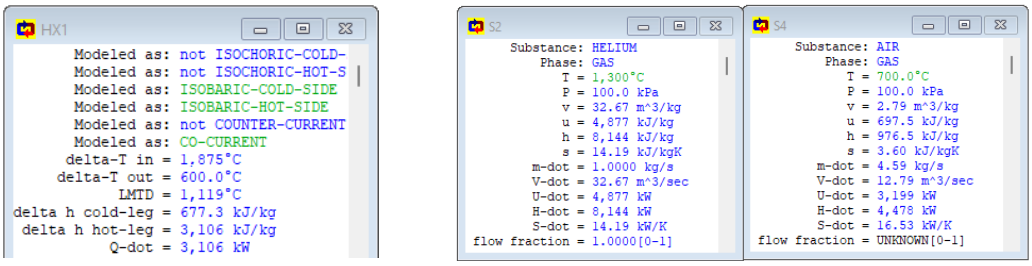


(a) HX-1 *meter* (b) *Meter* for hot and cold fluid exit

Figure 7. *Meters* for Case-1 (b)

Therefore, the LMTD = 1237°C, $\dot{m}_{cold}$=4.56 kg/s, and $\dot{Q}$=3106 kW.

(b) For the second part of the problem, one has to only change the type of heat exchanger from counter-current to co-current. The solved HX-1, s2, and s4 meters are as shown in **Figure 8**.



(a) HX-1 *meter* (b) *Meter* for hot and cold fluid exit

Figure 8. *Meters* for Case-1 (c)

In this case the LMTD is 1119°C, $\dot{m}_{cold}$=4.59 kg/s, and $\dot{Q}$=3106 kW.

Case-2: A heat exchanger heats water at 110 kPa from saturated liquid to saturated vapour. The temperature of flue gas (air at 110 kPa) entering and leaving is 1700 and 1000°C. The objective is to evaluate the LMTD, heat transfer rate and mass flow rate of air for 1 kg/s flow rate of water if the heat exchanger behaves as (i) counter flow (ii) parallel flow.

Solution:

The model build above (**Figure 4**) will be used.

(a) First, setting meter for s1 to s4 as shown in the **Figure 9**.

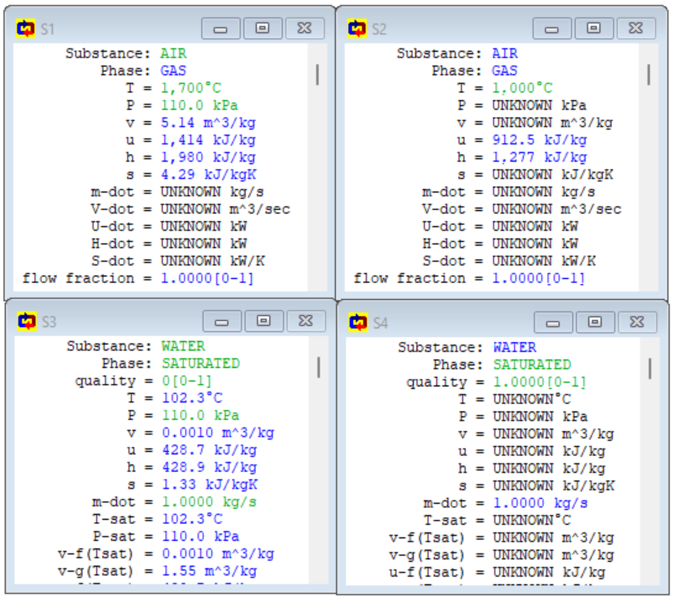
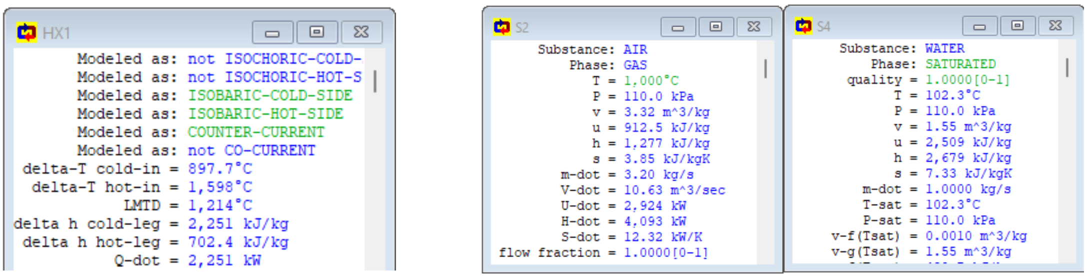


Figure 9. *Meters* for Case-2 (a)

The important point to note here is that as the cold fluid is water so for both inlet and exit one has to select the phase as 'saturated' and quality as 0 and 1 for inlet and exit respectively.

(b) Now for the heat exchanger set both the hot and cold fluid flow as isobaric and set HX-1 as counter-current (**Figure 10(a)**). Once this is done all the meters will get automatically solved (**Figure 10(b)**) and the desired parameters will be known (**Figure 10(a)**).

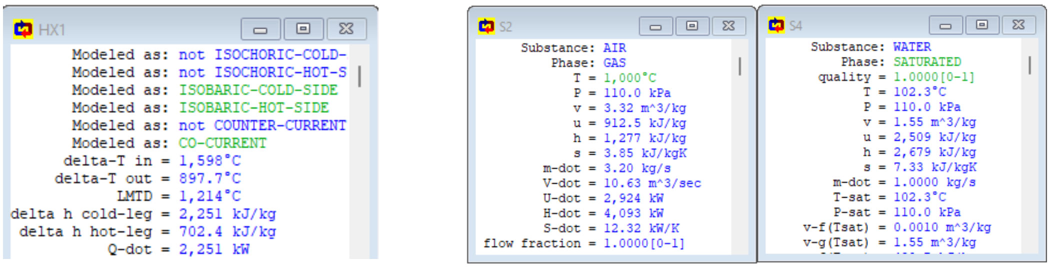


(a) HX-1 *meter* (b) *Meter* for hot and cold fluid exit

Figure 10. *Meters* for Case-2 (b)

This shows that the LMTD is 1214°C, $\dot{m}_{air}$=3.20 kg/s, and $\dot{Q}$=2251 kW.

(c) For parallel flow case, one has to only change the type of heat exchanger from counter-current to co-current. The solved HX-1, s2, and s4 meters are as shown in **Figure 11**.



(a) HX-1 *meter* (b) *Meter* for hot and cold fluid exit

Figure 11. *Meters* for Case-2 (c)

In this case the LMTD is 1214°C, $\dot{m}_{air}$=3.2 kg/s, and $\dot{Q}$=2251 kW. So, from the problem it is also clear that if one of the fluids is changing phase then the LMTD remains the same.

5. Conclusion

This article demonstrates the effectiveness of CyclePad software in modelling and analysing simple heat exchangers. By using its intuitive drag-and-drop interface and built-in analytical tools, a successfully modelling of both parallel and counterflow heat exchanger configurations have been done along with the evaluation of critical parameters such as the Log Mean Temperature Difference (LMTD), heat transfer rates, and mass flow rates under two case studies. In the first case heat exchange takes place between two gasses and it has been observed that the change of configuration (parallel or counter flow) has a substantive impact on LMTD. Whereas the second case deals with the water and air. Here, as the water is changing phase, so the LMTD is independent of the configuration. The study highlights CyclePad's utility as an educational tool, providing a visual and interactive platform for understanding thermodynamic principles. Future work could expand CyclePad's capabilities to include more complex models, dynamic simulations, and a broader component library, enhancing its potential for both educational purposes and professional engineering applications.

Conflict of interest

The authors declare no conflict of interest

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