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EXERGY-BASED MODELING AND EVALUATION OF INDUSTRIAL HEATERS USING AN OBJECT-ORIENTED SIMULATION SOFTWARE

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ABSTRACT

The Kaduna Refining and Petrochemicals Company (KRPC) Power Plant's Heaters that are used to warm the feed water before it enters the boilers are experiencing deterioration from their design output, which has increased the plant's fuel usage. A mathematical model) for the company's Heaters were developed using energy and exergy approach, and a simulation software for assessing the Heaters was developed using C# programming code and validated in open-source literature with a benchmark percentage deviation of 10%. The validated result revealed a maximum deviation of 2.18%, demonstrating the validity of the simulation software. The efficiencies, losses, and destructions of the Heaters were computed under design and operating condition as the input data were compiled and processed. The outcome showed that the energy efficiencies of Heater 1 and 2, which were each 96.99% at design conditions, were reduced to 87.38% and 84.17% at operating conditions, and the exergy efficiencies, which were each 10.20% at design conditions, were reduced to 6.89% and 3.73%. Similar to how exergy destruction increased from 2.5268 MW each at design condition to 3.0619 MW and 3.1659 MW at operating condition, energy losses from 0.2375 MW each at design condition increased to 1.1667 MW and 1.4635 MW at operating condition. Investigation revealed that, the Heaters are more energy and exergy efficient under design conditions than under operating conditions, and under operating conditions, more energy is lost and more exergy is destroyed than under design conditions. Additionally, it has been discovered that under both scenarios, energy efficiency is lower than exergy efficiency.

1.0 INTRODUCTION

Industrial heaters are heating systems that are used in industries, such as factories, warehouses, and manufacturing plants. These heaters are typically larger and more powerful than residential heating systems and are designed to heat large spaces or process materials at high temperatures. There are many different types of industrial heaters, including High Pressure (HP) Heaters. They are used in a variety of applications, including oil and gas processing, petrochemical refining, and power generation to warm the feed water before it enters the boiler (Ibrahim and Rahman, 2014). People must understand energy management in the modern world, so this kind of research is essential (Awad et al., 2018). The analyses are built on the principles of thermodynamics. Deteriorating HP heater performance has an effect on a plant's overall performance as well (Haider et al., 2014). The ability of the HP heaters to efficiently transfer heat accounts for the bulk of a conventional cogeneration plant's performance. As a result, the effectiveness of these heaters significantly affects the operation of the plant as a whole (Laskowski et al., 2015). The refinery produces fuels including gasoline, kerosene, lubricants, and drums, much to the delight of its clients (KRPC, 2022). The utilities and power plant sectors make up the power plant and utilities (PPU) department. The HP Heater, as depicted in Figure 1, which has been working to heat the feed water before it enters the boiler, is having trouble performing at the level of its design, which results in excessive fuel usage in the power plant.

2. SIMULATION

The simulation software aims to deal with these issues, revealing the magnitude of losses that occur in the HP Heater by detecting the losses, destructions, and efficiencies of the HP Heater. It will also serve as a guide for the company's management regarding the maintenance schedule for the plant (Elghool et al., 2017).

The evaluation not only assesses but also recommends changes to be made to boost the system's efficiency (Yusof et al., 2018). Several .NET Framework-based apps can be produced using Microsoft's C-SHAPE, a cutting-edge, all-purpose, object-oriented programming language. It is an effective language that is frequently used to create Windows programs, mobile applications, online applications, and other types of applications. An interface in C# is a way to define a contract for how a class or struct should interact with other code The class or struct must then provide an implementation for each of the members of the interface (C# program, 2022).

Figure 1. The High-Pressure Heaters

Heat exchangers simulation software was created using Python code and validated using free and open-source literature. High levels of agreement between the validation result and the literature backed up the program's validity (Abubakar et al., 2020). The most exergy degradation was discovered to be coming from the steam generator, and a validated simulation result via MATLAB showed that the theoretical estimate matched the simulation result perfectly (Altarawneh et al., 2022). When a cogeneration facility was analyzed using a MATLAB calculating tool, it was discovered that the steam generator is where the majority of exergy is lost (Kumar et al., 2020).

3. RELATED LITERATURES

According to a study, a degree Celsius difference in water temperature has an impact on the pressure and heating rate of a plant's condenser (Pattanayak et al., 2019). A study reveals that power generation increases in tandem with coal consumption. Energy was destroyed at a rate of roughly 16% more when fuel consumption rose by 40 kg/s (Khaleel et al., 2022). An increase in plant efficiency from 52.3% to 54.15% led to an increase in output from 330 MW to 412 MW, as efficiency and output are strongly correlated (Chen et al., 2022). The appropriate pressures for bleeding off steam are simultaneously obtained for heat exchangers. The highest efficiencies are used to guide a multivariable optimization (Khaleel et al., 2022).

Similarly, the validated results were found to be sufficient when the MATLAB simulation program of a coal-fired power station was evaluated under various load circumstances (Kumar et al., 2019). According to a factory analysis, the combustion chamber loses the most energy (73%), and as the temperature of the surrounding air rises, so do the plant's energy production and efficiency (Bataineh et al., 2020). According to the 1.42% against 10% benchmark verified simulation program analysis, the HP Pumps have greater efficiency under design conditions than under operating conditions, and during operating conditions, more energy is lost and more exergy is destroyed than under design conditions (Abubakar et al., 2022). A study has shown that minimizing the difference between water and steam temperatures leads to a reduction in the amount of energy lost in the plant (Khaleel et al., 2021). Basic tests for verifying asymptotic behavior have been used to validate an object-oriented reciprocating compressor simulation code, ensuring error-free code and physically accurate outcomes (Damle et al., 2011). The step-by-step process for creating the boiler's mathematical model was detailed as the cogeneration plant of a refinery was analyzed (Abubakar et al., 2020). Exergy-based simulation software was developed and verified using open-source literature, and it showed strong correlations in both the qualitative and quantitative dimensions. An energy conversion process plant was then examined using it (Zoder et al., 2018). Software was used to assess a 200 MW power plant. It was discovered that the boiler wasted more energy than the condenser overall (Ahmadi et al., 2016).

3. METHODS

3.1 The Cogeneration Plant

The deaerators change water from 45°C, 9 bars, and 1 ppm dissolved oxygen to 125°C, 2.5 bars, and 0.007 ppm dissolved oxygen, respectively. After passing through the pumps, the water's pressure increased to 60.5 bars. The water is then heated to 140^0C and fed to the steam generators at a rate of 270 t/hr by heaters. At 185°C and 52.4bar, it turns into saturated steam. The steam is heated to a maintained dry temperature of 412^0C and 42.5bar at the exit by the superheaters and attemperators.

3.2 Pressure Generation

High-pressure pumps and electric generators are both run by superheated steam. The medium-pressure steam generated by the pumps and generators powers the lower pumps and heats the water in the heaters; as a result, it condenses through a vacuum and is pushed to the condensate tank, where it is recycled to the Demin unit as depicted in figure 3.1. Deaerators are supplied with steam from the lower pumps and condensate from the heaters (Tokyo, 1981).

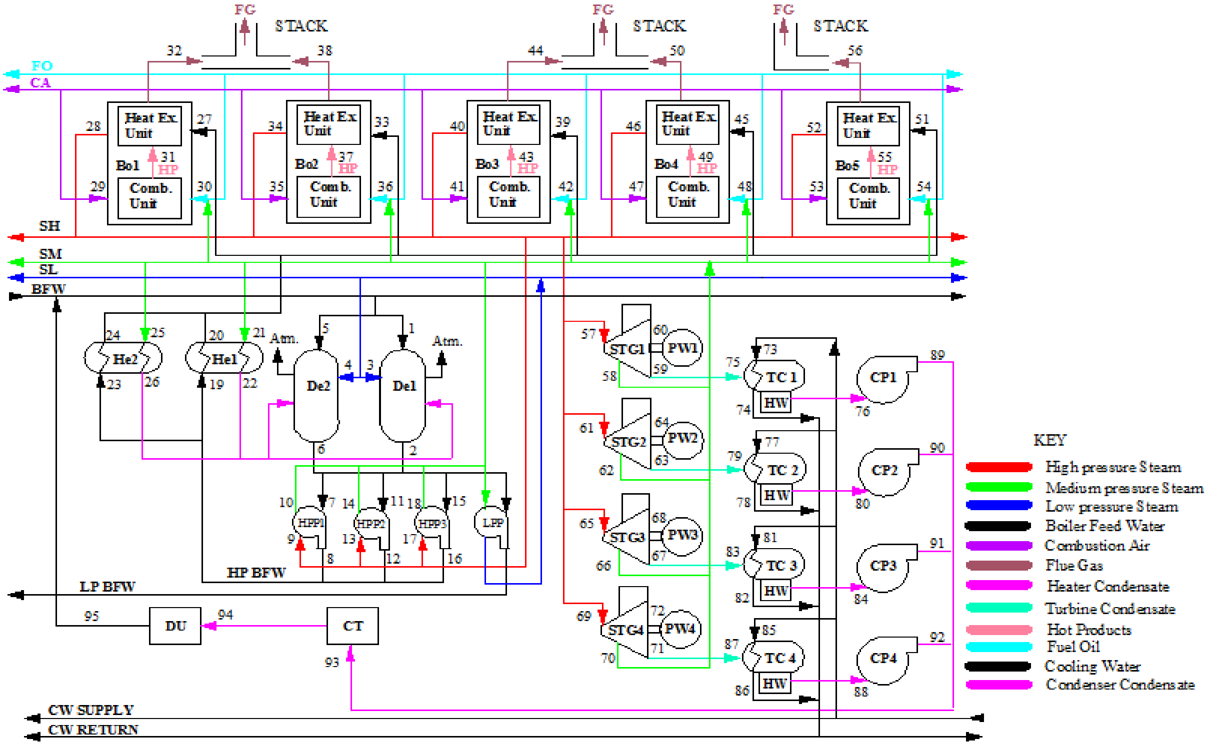


Figure 2. Process of the cogeneration plant

Nomenclature

BFW	Boiler feed water
CDT	Condensate
CW	Cooling water
CA	Combustion air
ESM	Extracted medium pressure steam
CSM	Condensed medium pressure steam
De	Deaerator
HPP	High pressure pump
LPP	Low pressure pump
He	Heater
Bo	Boiler
STG	Steam turbine generator
TC	Turbine condenser
HW	Hot well
CP	Condensate pump
CT	Condensate tank
DU	Demineralized unit
CU	Combustion unit
HEU	Heat exchange unit
KRPC	Kaduna refining and petro-chemical company
HHV	high heating value of fuel (kJ/kg)
LHV	low heating value of fuel (kJ/kg)
AAF	actual air-fuel ratio of fuel (kg of air/kg of fuel)
$\dot{E}$	Energy flow rate (kJ/s)
$\dot{E}_X$	Exergy flow rate (kJ/s)
$\dot{E}_{XD}$	Exergy destruction (kJ/s)
C_p	Specific heat capacity (kJ/kgK)
$\dot{M}$	Mass flow rate (Kg/s)
$\dot{Q}$	Rate of heat transfer to the system (kJ/s)

$\dot{Q}_L$	Rate of heat loss (kJ/s)
$\dot{W}$	Rate of work done by the system (kJ/s)
PW	Power produce by the system (kJ/s)
h	specific enthalpy (J/Kg)
s	specific entropy (J/Kg K)
P_o	Atmospheric pressure (bar)
T_o	Atmospheric Temperature (°C)

Greek letters

η_I	Energy efficiency (%)
η_{II}	Exergy efficiency (%)
ε	specific exergy (kJ/Kg)

Sub_ and superscripts

SH	High pressure steam
SM	Medium pressure steam
SL	Low pressure steam
FW	Feed water
FO	Fuel oil
F	Fuel
FG	Flue gas
A	Air
S	Steam
comb	Combustion
HP	Hot products
0	reference state

A sketch of the plant's process was made after investigating its operational procedures. The component-wise approach and a review of the thermodynamic laws were used to construct the general thermodynamic model of a component.

3.3 Mathematical Model of the High-Pressure Heaters

A generic thermodynamic model and the process of the cogeneration plant were used to build the specific thermodynamic model of the high-pressure heaters. Only heaters 1 and 2, which are seen in Figures 3.2 and 3.3, were examined throughout this research project.

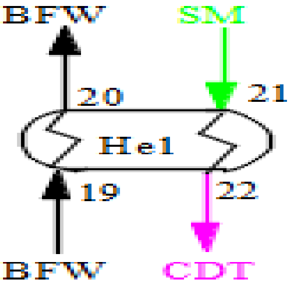


Figure 3. High-Pressure Heater 1

3.4 Energy Efficiency on High-Pressure Heater 1

Energy efficiency ($\eta_{I(\text{He1})}$):

$$\frac{\text{Energy flowrate of FW outlet} - \text{Energy flowrate of FW inlet}}{\text{Energy flowrate of SM inlet} - \text{Energy flowrate of CDT outlet}} \times 100\%$$

Exergy efficiency ($\eta_{II(\text{He1})}$):

$$\frac{\text{Exergy flowrate of FW outlet} - \text{Exergy flowrate of FW outlet}}{\text{Exergy flowrate of SM inlet} - \text{Exergy flowrate of CDT outlet}} \times 100\%$$

Energy loss ($\dot{Q}_{L(He1)}$):

$$(\text{Energy flowrate of SM inlet} + \text{Energy flowrate of FW inlet}) - (\text{Energy flowrate of FW outlet} + \text{Energy flowrate of CDT outlet})$$

Exergy Destruction ($\dot{E}_{XD(He1)}$):

$$(\text{Exergy flowrate of SM inlet} + \text{Exergy flowrate of FW inlet}) - (\text{Exergy flowrate of FW outlet} + \text{Exergy flowrate of CDT outlet})$$

Where:

Energy flowrate of FW inlet ($\dot{E}_{19}$) $= \dot{M}_{19}h_{19}$ (1)
Energy flowrate of FW outlet ($\dot{E}_{20}$) $= \dot{M}_{20}h_{20}$ (2)
Energy flowrate of SM inlet ($\dot{E}_{21}$) $= \dot{M}_{21}h_{21}$ (3)
Energy flowrate of CDT outlet ($\dot{E}_{22}$) $= \dot{M}_{22}h_{22}$ (4)
Exergy flowrate of BFW inlet ($\dot{Ex}_{19}$) $= h_{19} - T_O s_{19}$ (5)
Exergy flowrate of BFW outlet ($\dot{Ex}_{20}$) $= h_{20} - T_O s_{20}$ (6)
Exergy flowrate of SM inlet ($\dot{Ex}_{21}$) $= h_{21} - T_O s_{21}$ (7)
Exergy flowrate of CDT 0utlet ($\dot{Ex}_{22}$) $= h_{22} - T_O s_{22}$ (8)

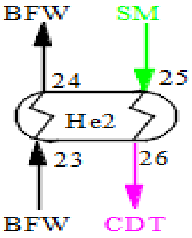


Figure 4. High-Pressure Heater 2

3.5 Energy Efficiency on High-Pressure Heater 2

Energy efficiency ($\eta_{\mathrm{I(He2)}}$):
$$\frac{\text{Energy flowrate of FW outlet} - \text{Energy flowrate of FW inlet}}{\text{Energy flowrate of SM inlet} - \text{Energy flowrate of CDT outlet}} \times 100\%$$
Exergy efficiency ($\eta_{\mathrm{II(He2)}}$):
$$\frac{\text{Exergy flowrate of FW outlet} - \text{Exergy flowrate of FW outlet}}{\text{Exergy flowrate of SM inlet} - \text{Exergy flowrate of CDT outlet}} \times 100\%$$
Energy loss ($\dot{Q}_{L(He2)}$):
$$(\text{Energy flowrate of SM inlet} + \text{Energy flowrate of FW inlet}) - (\text{Energy flowrate of FW outlet} + \text{Energy flowrate of CDT outlet})$$

Exergy Destruction ($\dot{E}_{XD(He2)}$):
$$(\text{Exergy flowrate of SM inlet} + \text{Exergy flowrate of FW inlet}) - (\text{Exergy flowrate of FW outlet} + \text{Exergy flowrate of CDT outlet})$$

Where:
Energy flowrate of FW inlet ($\dot{\mathrm{E}}_{23}$) $= \dot{M}_{23}h_{23}$ (9)
Energy flowrate of FW outlet ($\dot{\mathrm{E}}_{24}$) $= \dot{M}_{24}h_{24}$ (10)
Energy flowrate of SM inlet ($\dot{\mathrm{E}}_{25}$) $= \dot{M}_{25}h_{25}$ (11)
Energy flowrate of CDT outlet ($\dot{\mathrm{E}}_{26}$) $= \dot{M}_{26}h_{26}$ (12)
Exergy flowrate of BFW inlet ($\dot{\mathrm{Ex}}_{23}$) $= h_{23} - T_O s_{23}$ (13)
Exergy flowrate of BFW outlet ($\dot{\mathrm{Ex}}_{24}$) $= h_{24} - T_O s_{24}$ (14)
Exergy flowrate of SM inlet ($\dot{\mathrm{Ex}}_{25}$) $= h_{25} - T_O s_{25}$ (15)
Exergy flowrate of CDT outlet ($\dot{\mathrm{Ex}}_{26}$) $= h_{26} - T_O s_{26}$ (16)

3.6 Simulation Software of the High-Pressure Heaters

The simulation software, which comprises the programming codes and users' interfaces, was designed and implemented using the C# programming language. These interfaces include the menu preparation, component selection, input data, and output data interfaces. The flowchart of algorithms and interfaces is shown in Figures 5–9, respectively.

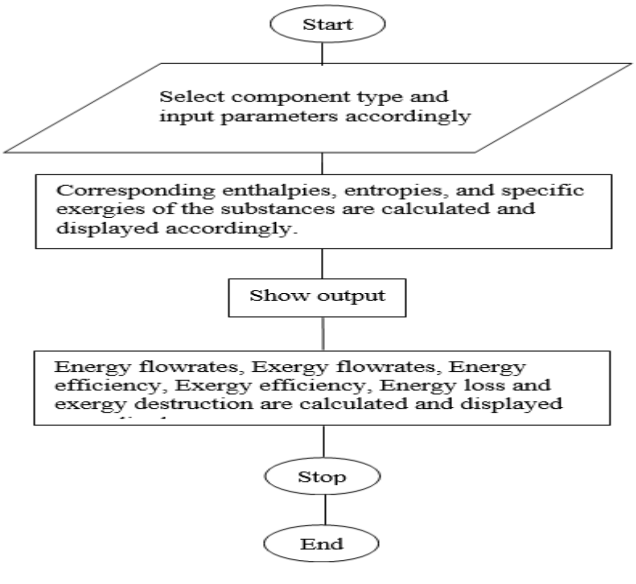
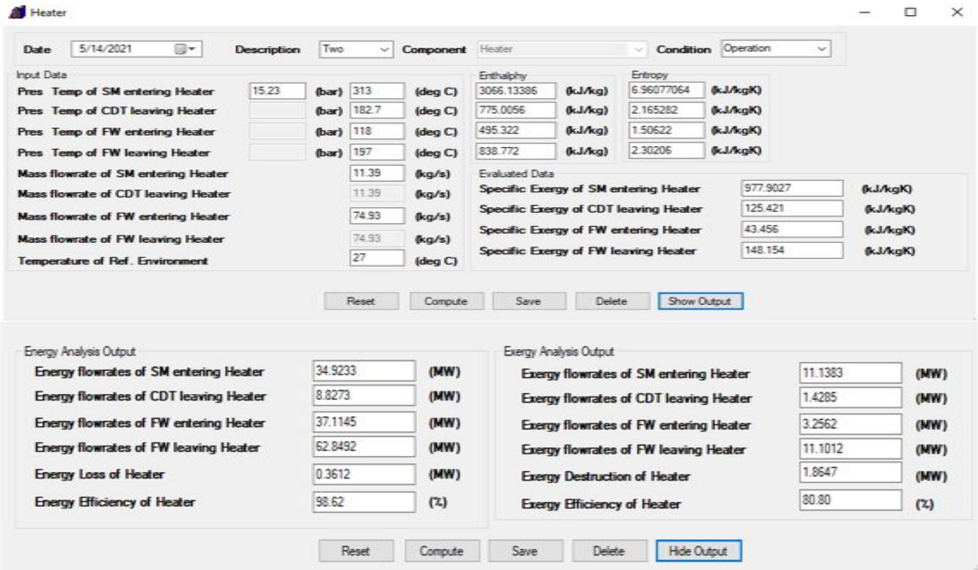


Figure 5. Simulation algorithm



Date 5/14/2021 Description Two Component Heater Condition Operation

Input Data

Pres Temp of SM entering Heater 15.23 (bar) 313 (deg C)
Pres Temp of CDT leaving Heater (bar) 182.7 (deg C)
Pres Temp of FW entering Heater (bar) 118 (deg C)
Pres Temp of FW leaving Heater (bar) 197 (deg C)
Mass flowrate of SM entering Heater 11.39 (kg/s)
Mass flowrate of CDT leaving Heater 11.39 (kg/s)
Mass flowrate of FW entering Heater 74.93 (kg/s)
Mass flowrate of FW leaving Heater 74.93 (kg/s)
Temperature of Ref. Environment 27 (deg C)

Enthalphy
3066.13386 (kJ/kg)
775.0056 (kJ/kg)
495.322 (kJ/kg)
838.772 (kJ/kg)

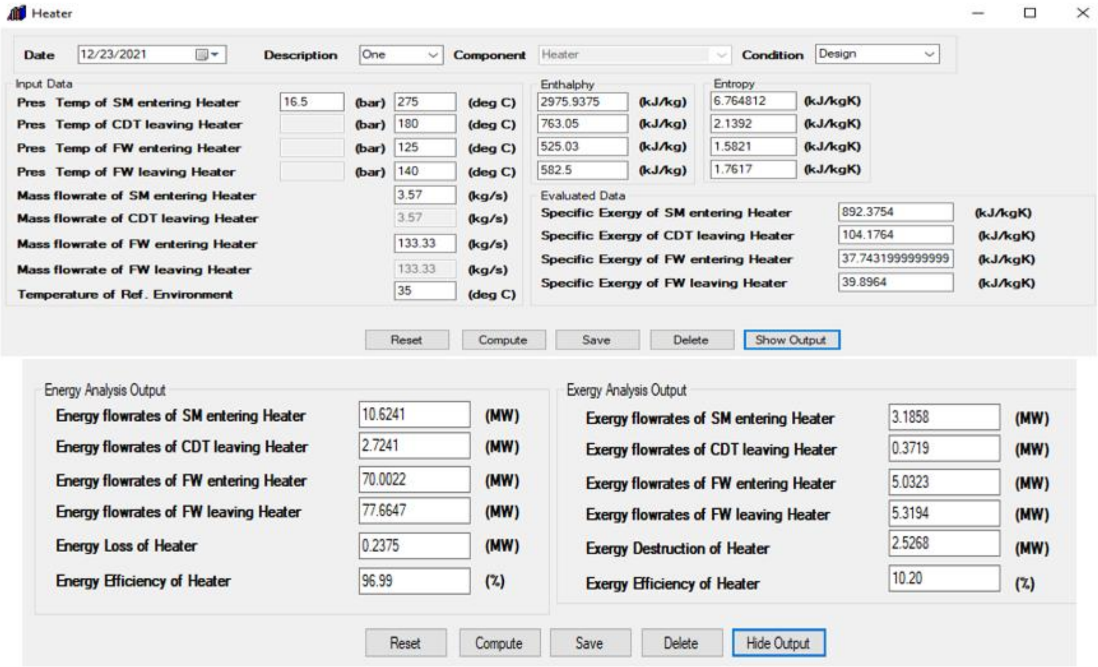
Entropy
6.96077064 (kJ/kgK)
2.165282 (kJ/kgK)
1.50622 (kJ/kgK)
2.30206 (kJ/kgK)

Evaluated Data
Specific Exergy of SM entering Heater 977.9027 (kJ/kgK)
Specific Exergy of CDT leaving Heater 125.421 (kJ/kgK)
Specific Exergy of FW entering Heater 43.456 (kJ/kgK)
Specific Exergy of FW leaving Heater 148.154 (kJ/kgK)

Energy Analysis Output
Energy flowrates of SM entering Heater 34.9233 (MW)
Energy flowrates of CDT leaving Heater 8.8273 (MW)
Energy flowrates of FW entering Heater 37.1145 (MW)
Energy flowrates of FW leaving Heater 62.8492 (MW)
Energy Loss of Heater 0.3612 (MW)
Energy Efficiency of Heater 98.62 (%)

Exergy Analysis Output
Exergy flowrates of SM entering Heater 11.1383 (MW)
Exergy flowrates of CDT leaving Heater 1.4285 (MW)
Exergy flowrates of FW entering Heater 3.2562 (MW)
Exergy flowrates of FW leaving Heater 11.1012 (MW)
Exergy Destruction of Heater 1.8647 (MW)
Exergy Efficiency of Heater 80.80 (%)

Figure 6. Literature input data, with simulation output data



Date 12/23/2021 Description One Component Heater Condition Design

Input Data

Pres Temp of SM entering Heater 16.5 (bar) 275 (deg C)
Pres Temp of CDT leaving Heater (bar) 180 (deg C)
Pres Temp of FW entering Heater (bar) 125 (deg C)
Pres Temp of FW leaving Heater (bar) 140 (deg C)
Mass flowrate of SM entering Heater 3.57 (kg/s)
Mass flowrate of CDT leaving Heater 3.57 (kg/s)
Mass flowrate of FW entering Heater 133.33 (kg/s)
Mass flowrate of FW leaving Heater 133.33 (kg/s)
Temperature of Ref. Environment 35 (deg C)

Enthalphy
2975.9375 (kJ/kg)
763.05 (kJ/kg)
525.03 (kJ/kg)
582.5 (kJ/kg)

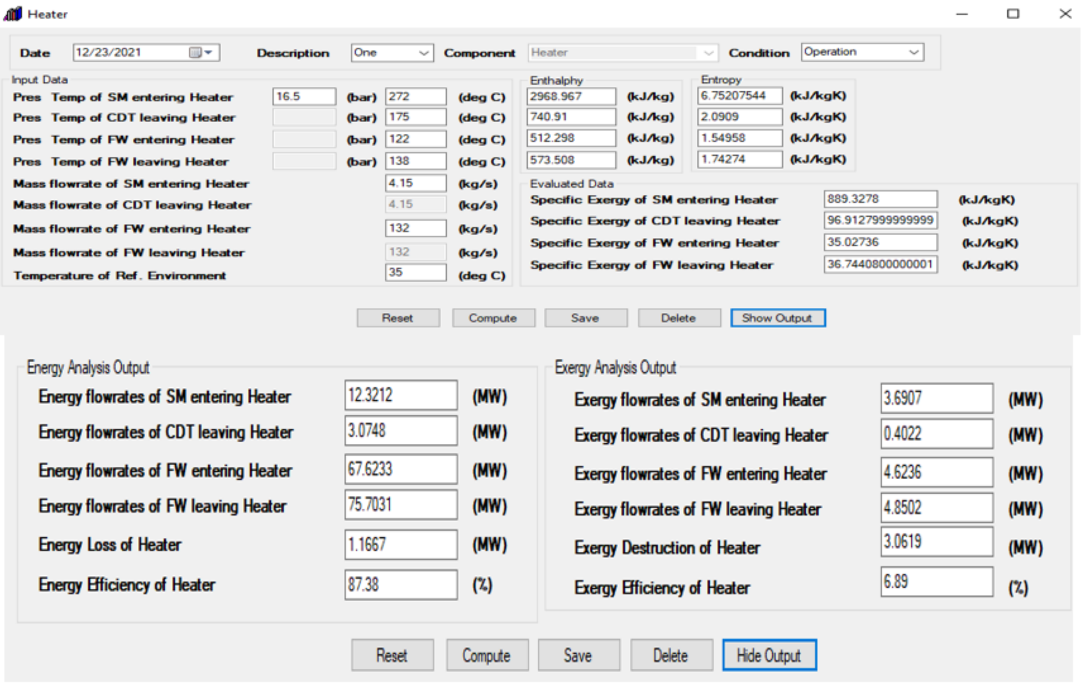
Entropy
6.764812 (kJ/kgK)
2.1392 (kJ/kgK)
1.5821 (kJ/kgK)
1.7617 (kJ/kgK)

Evaluated Data
Specific Exergy of SM entering Heater 892.3754 (kJ/kgK)
Specific Exergy of CDT leaving Heater 104.1764 (kJ/kgK)
Specific Exergy of FW entering Heater 37.7431999999999 (kJ/kgK)
Specific Exergy of FW leaving Heater 39.8964 (kJ/kgK)

Energy Analysis Output
Energy flowrates of SM entering Heater 10.6241 (MW)
Energy flowrates of CDT leaving Heater 2.7241 (MW)
Energy flowrates of FW entering Heater 70.0022 (MW)
Energy flowrates of FW leaving Heater 77.6647 (MW)
Energy Loss of Heater 0.2375 (MW)
Energy Efficiency of Heater 96.99 (%)

Exergy Analysis Output
Exergy flowrates of SM entering Heater 3.1858 (MW)
Exergy flowrates of CDT leaving Heater 0.3719 (MW)
Exergy flowrates of FW entering Heater 5.0323 (MW)
Exergy flowrates of FW leaving Heater 5.3194 (MW)
Exergy Destruction of Heater 2.5268 (MW)
Exergy Efficiency of Heater 10.20 (%)

Figure 7. HP Heater interphase at design condition



Date 12/23/2021
Description One
Component Heater
Condition Operation

Input Data

	Pres (bar)	Temp (deg C)	Enthalphy (kJ/kg)	Entropy (kJ/kgK)
Pres Temp of SM entering Heater	16.5	272	2968.967	6.75207544
Pres Temp of CDT leaving Heater		175	740.91	2.0909
Pres Temp of FW entering Heater		122	512.298	1.54958
Pres Temp of FW leaving Heater		138	573.508	1.74274

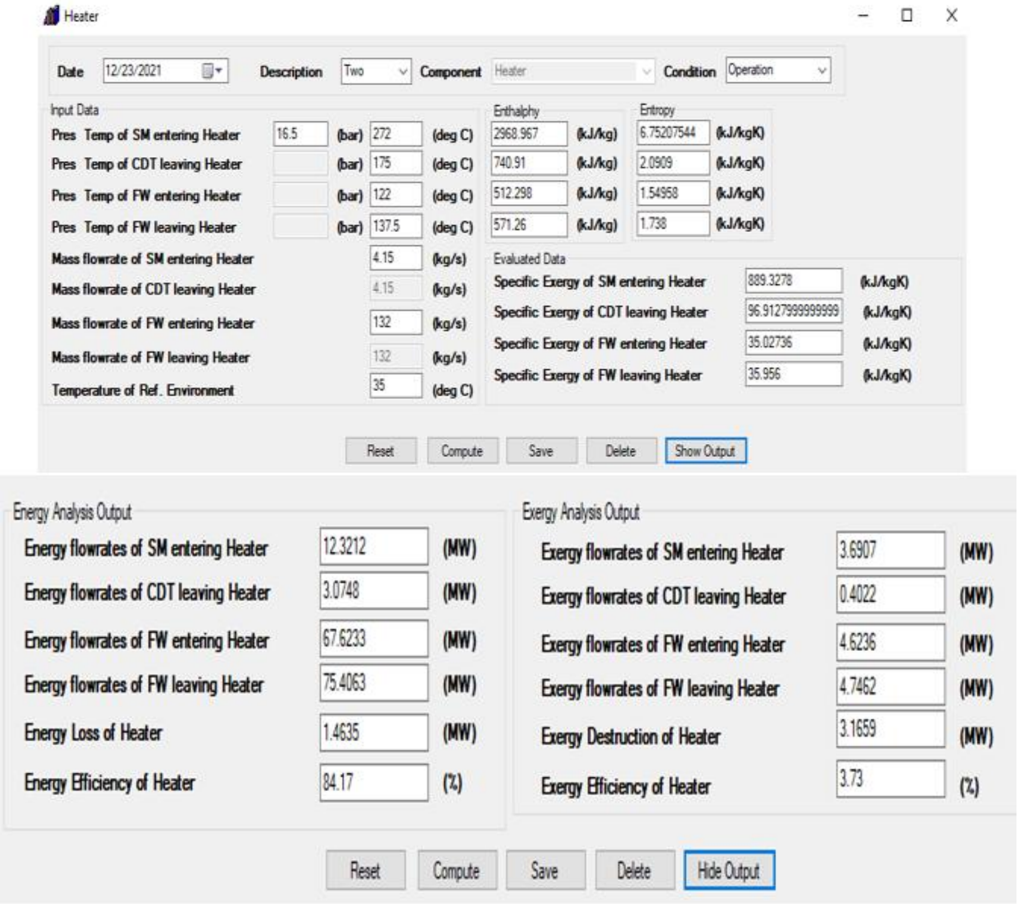
Mass flowrate of SM entering Heater 4.15 (kg/s)
Mass flowrate of CDT leaving Heater 4.15 (kg/s)
Mass flowrate of FW entering Heater 132 (kg/s)
Mass flowrate of FW leaving Heater 132 (kg/s)
Temperature of Ref. Environment 35 (deg C)

Evaluated Data
Specific Exergy of SM entering Heater 889.3278 (kJ/kgK)
Specific Exergy of CDT leaving Heater 96.9127999999999 (kJ/kgK)
Specific Exergy of FW entering Heater 35.02736 (kJ/kgK)
Specific Exergy of FW leaving Heater 36.7440800000001 (kJ/kgK)

Energy Analysis Output
Energy flowrates of SM entering Heater 12.3212 (MW)
Energy flowrates of CDT leaving Heater 3.0748 (MW)
Energy flowrates of FW entering Heater 67.6233 (MW)
Energy flowrates of FW leaving Heater 75.7031 (MW)
Energy Loss of Heater 1.1667 (MW)
Energy Efficiency of Heater 87.38 (%)

Exergy Analysis Output
Exergy flowrates of SM entering Heater 3.6907 (MW)
Exergy flowrates of CDT leaving Heater 0.4022 (MW)
Exergy flowrates of FW entering Heater 4.6236 (MW)
Exergy flowrates of FW leaving Heater 4.8502 (MW)
Exergy Destruction of Heater 3.0619 (MW)
Exergy Efficiency of Heater 6.89 (%)

Figure 8. HP Heater 1 interphase at operating condition



Date 12/23/2021
Description Two
Component Heater
Condition Operation

Input Data

	Pres (bar)	Temp (deg C)	Enthalphy (kJ/kg)	Entropy (kJ/kgK)
Pres Temp of SM entering Heater	16.5	272	2968.967	6.75207544
Pres Temp of CDT leaving Heater		175	740.91	2.0909
Pres Temp of FW entering Heater		122	512.298	1.54958
Pres Temp of FW leaving Heater		137.5	571.26	1.738

Mass flowrate of SM entering Heater 4.15 (kg/s)
Mass flowrate of CDT leaving Heater 4.15 (kg/s)
Mass flowrate of FW entering Heater 132 (kg/s)
Mass flowrate of FW leaving Heater 132 (kg/s)
Temperature of Ref. Environment 35 (deg C)

Evaluated Data
Specific Exergy of SM entering Heater 889.3278 (kJ/kgK)
Specific Exergy of CDT leaving Heater 96.9127999999999 (kJ/kgK)
Specific Exergy of FW entering Heater 35.02736 (kJ/kgK)
Specific Exergy of FW leaving Heater 35.956 (kJ/kgK)

Energy Analysis Output
Energy flowrates of SM entering Heater 12.3212 (MW)
Energy flowrates of CDT leaving Heater 3.0748 (MW)
Energy flowrates of FW entering Heater 67.6233 (MW)
Energy flowrates of FW leaving Heater 75.4063 (MW)
Energy Loss of Heater 1.4635 (MW)
Energy Efficiency of Heater 84.17 (%)

Exergy Analysis Output
Exergy flowrates of SM entering Heater 3.6907 (MW)
Exergy flowrates of CDT leaving Heater 0.4022 (MW)
Exergy flowrates of FW entering Heater 4.6236 (MW)
Exergy flowrates of FW leaving Heater 4.7462 (MW)
Exergy Destruction of Heater 3.1659 (MW)
Exergy Efficiency of Heater 3.73 (%)

Figure 9.: HP Heater 2 interphase at operating condition

3.7 Validation of the Simulation Software

Table 3.1 shows the input data together with the high-pressure heater's associated enthalpy and entropy for both cases. The outputs of the software and those of an Indian power plant using free and open-source literature were compared, with a benchmark percentage error of 10% (Pilankar and Kale 2016). The validated result revealed a maximum inaccuracy of 2.18%, which might have been brought on by some default assumptions and settings. As a result, this confirms the accuracy of the simulation software as displayed in tables 3.2 and 3.3.

Table 1. Input data of hp heater at literature and simulation condition

Component	Point	Fluid Type	Input			Literature		Simulation	
			Pressure (bar)	Temperature (^{0}C)	Mass flowrate (kg/s)	Enthalpy (kJ/kg)	Entropy (kJ/kg.K)	Enthalpy (kJ/kg)	Entropy (kJ/kg.K)
HP Heater	15a	SM in	15.23	313	11.39	3066.48	6.962	3066.1339	6.9608
	3a	CDT out	10.66	183	11.39	776.68	2.169	775.0056	2.1653
	9a	FW in	127.52	118	74.93	495.80	1.474	495.322	1.5062
	10a	FW out	127.52	197	74.93	843.84	2.285	838.772	2.3021

Table 2. Enthalpy and entropy percentage error

Component	Point	Fluid Type	Enthalpy (kJ/kg) Literature	Enthalpy (kJ/kg) Simulation	% Error	Entropy (kJ/kgK) Literature	Entropy (kJ/kgK) Simulation	% Error
HP Heater	15a	SM in	3066.48	3066.1339	0.01	6.962	6.9608	0.02
	3a	CDT out	776.68	775.0056	0.22	2.169	2.1653	0.17
	9a	FW in	495.80	495.322	0.10	1.474	1.5062	2.18
	10a	FW out	843.84	838.772	0.60	2.285	2.3021	0.75

Table 3. Analysis Index Percentage Error

Component	Analysis Index	Literature	Simulation	% Error
HP Heater	Energy Efficiency (%)	100	98.62	1.38
	Energy Loss (MW)	0.366	0.3612	1.31
	Exergy Efficiency (%)	80.19	80.8	0.76
	Exergy Destruction (MW)	1.889	1.8647	1.29

3.8 Evaluation of the HP Heaters

The flow rates of the heaters at each location were estimated and indicated as the input data were collected and processed. The heaters' efficiencies, energy losses, and exergy destructions are then independently estimated under design and operational conditions. Tables 3 and 4 display the input data and the contrasted analytical outputs for the heaters under design and operational conditions.

Table 4. Input Data of HP Heaters at Design and Operating Condition

Component	Point	Fluid Type	Pressure (bar)	Temperature (^{0}C)	Mass flowrate (kg/s)	Enthalpy (kJ/kg)	Entropy (kJ/kg.K)	Specific exergy (kJ/kg.K)	Energy flowrate (MW)	Exergy flowrate (MW)
DESIGN CONDITION										
HP Heater	19	FW in	-	125	133.33	525.03	1.5821	37.74319999	70.0022	5.0323
	20	FW out	-	140	133.33	582.5	1.7617	39.8964	77.6647	5.3194
	21	SM in	16.5	275	3.57	2975.938	6.764812	892.3754	10.6241	3.1858
	22	CDT out	-	180	3.57	763.05	2.1392	104.1764	2.7241	0.3719
OPERATING CONDITION										
HP Heater 1	19	FW in	-	122	132	512.298	1.54958	35.02736	67.6233	4.6236
	20	FW out	-	138	132	573.508	1.74274	36.74408	75.7031	4.8502
	21	SM in	16.5	272	4.15	2968.967	6.75207544	889.3278	12.3212	3.6907
	22	CDT out	-	175	4.15	740.91	2.0909	96.9127999	3.0748	0.4022
HP Heater 2	23	FW in	-	122	132	512.298	1.54958	35.02736	67.6233	4.6236
	24	FW out	-	137.5	132	571.26	1.738	35.956	75.4063	4.7462
	25	SM in	16.5	272	4.15	2968.967	6.75207544	889.3278	12.3212	3.6907
	26	CDT out	-	175	4.15	740.91	2.0909	96.9127999	3.0748	0.4022

TABLE 5. Comparison Between Design and Operating Condition

Component	Analysis index	Condition		Difference
		Design	Operating	
HP Heater 1	Energy Efficiency (%)	96.99	87.38	9.61
	Energy Loss (MW)	0.2375	1.1667	0.93
	Exergy Efficiency (%)	10.20	6.89	3.31
	Exergy Destruction (MW)	2.5268	3.0619	0.54
HP Heater 2	Energy Efficiency (%)	96.99	84.17	12.82
	Energy Loss (MW)	0.2375	1.4635	1.23
	Exergy Efficiency (%)	10.20	3.73	6.47
	Exergy Destruction (MW)	2.5268	3.1659	0.64

4. RESULTS AND DISCUSSION

In the case of validation, the outputs from the software for the high-pressure heater were contrasted with the norm in the literature. But when assessing the heaters, similar comparisons were made between the operating circumstances and design outcomes. The percentage errors and variances that were discovered are displayed on the accompanying graphs.

4.1 Validation Analysis of the Software

The percentage inaccuracy of the analysis ranges from 0.01% to 2.18%. In the entropy of water entering the heater, the greatest percentage error of 2.18%, which is less than the benchmark of 10%, was discovered. Figures 10, 11, and 12 present these inaccuracies in pictorial form, accordingly.

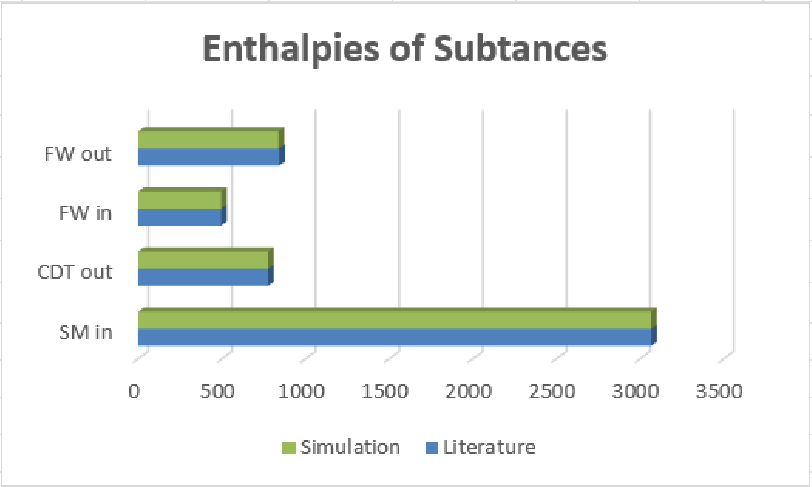


Figure 10. Enthalpy variance at both scenarios

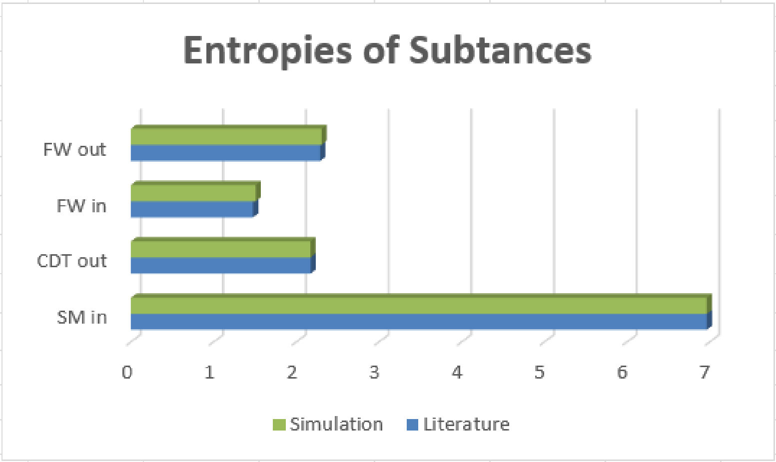


Figure 11. Entropy variance at both scenarios

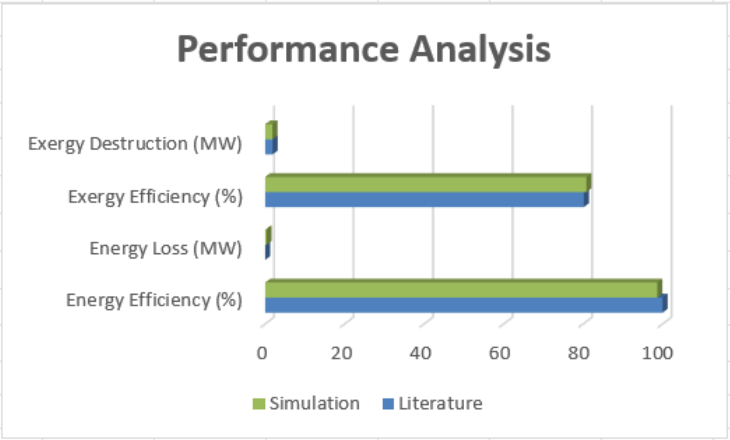


Figure 12. Analysis indices variance at both scenarios

4.2 Performance Analysis of HP Heater 1

Performance analysis has been done on HP Heater 1 of the power plant under design and operational circumstances. Figure 4.4 shows the performance index graph. The graph shows that energy and exergy efficiency, which were 96.99% and 10.20% at design condition, are now 87.38% and 6.89%, respectively, while energy loss and exergy destruction, which were 0.2375 MW and 2.5268 MW at design condition, are now 1.1667 MW and 3.0619 MW, respectively, at operating condition.

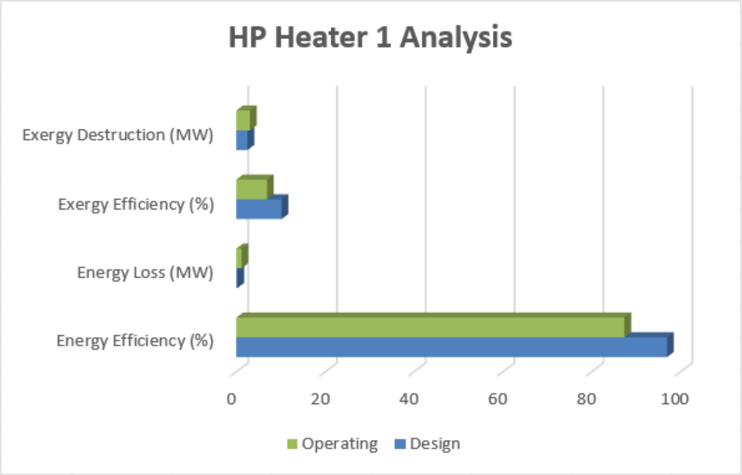


Figure 13. Performance index of HP Heater 1 at both conditions

4.3 Performance Analysis of HP Heater 2

A performance evaluation of HP Heater 2 in the power plant was carried out under both design and operational conditions. Figures 13 and 14 depict the performance index graph. The graph shows that the energy and exergy efficiency, which were 96.99% and 10.20% at design condition, were reduced to 84.17% and 3.73% at operating condition, while the energy loss and exergy destruction, which were 0.2375 MW and 2.5268 MW at design condition, were increased to 1.4635 MW and 3.1659 MW, respectively.

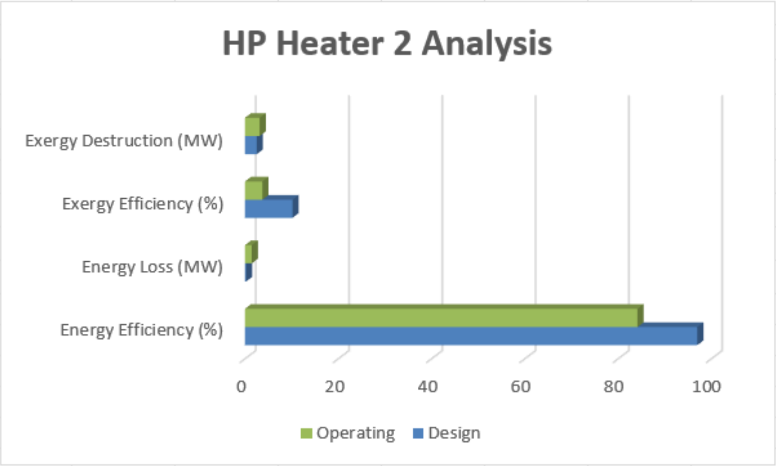


Figure 14. Performance indices of HP Heater 2 at both conditions

5. CONCLUSION

This study encourages the creation of simulation software using object-oriented programming languages. The HP Heater thermodynamic model, which was converted into a simulation software, had a maximum percentage error of 2.18% when compared to the benchmark percentage error of 10%. This demonstrated the model's applicability. The investigation showed that the HP Heaters at the KRPC power plant had higher energy and exergy efficiency at design than in operating conditions, and there is greater energy loss and exergy destruction in operating conditions than in design conditions. These are a result of the power plant's defective control system.

As a result, the KRPC power plant's control system needs to be in good working order if it is not constantly operated at design conditions. The company's management will receive sound direction regarding how to maintain the plant. Furthermore, it is anticipated that this research endeavor will be of utmost importance to scientists, educators, and professionals in energy science and engineering.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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