Enhancing Heat Transfer Efficiency: Nanofluid Integration in Diverse Systems and Coiled Heat Exchangers Using L9 Orthogonal Array

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Abstract - *The utilization of heat exchangers and nanofluids for improved heat transfer is the main topic of this paper discussion of research on heat exchange and thermal performance in diverse systems. The research investigates the effects of nanofluids on cooling tower-based central air conditioning systems, car radiators, and vapor compression refrigeration systems. The studies also look into the usage of nanofluids in shell and helical coiled tube heat exchangers, the optimization of helix coiled tube heat exchangers, and the impact of turbulators. The effects of inclination angle and cross-sectional form in helical coiled tubes are also investigated. This work compares the effectiveness and thermal properties, including heat transfer rate, convective heat transfer coefficient, logarithmic mean temperature difference (LMTD), and convective heat transfer coefficient, between a shell and tube heat exchanger and a helical coil using computational fluid dynamics (CFD). The heat transfer fluid in the study is nanofluid, and helical coils with varying sweep angles (10, 20, and 30) are designed. ANSYS software is used in the computational process to virtually build a double helical coiled tube heat exchanger utilizing dimensions derived from experimental data. The cold fluid is pumped via copper tubes with different mass flow rates and specific characteristics. The outcomes of experiments are used to validate the virtual model. Then, using established formulas, a nanofluid is added and its characteristics are computed. A number of response variables and factors, such as heat transfer rate, LMTD, overall heat transfer coefficient, and heat exchanger effectiveness, are used to compare the outcomes. Surfactants are added to the nanofluid to provide stability, and the volume fraction is set at 0.75%. The number of experiments and parameters are determined using a design of experiments technique with the L9 orthogonal array. The study investigates the possible advantages of utilizing a hybrid nanofluid in a double helix coiled heat exchanger. This method's result is dependent on a number of variables, such as heat exchanger design, operating conditions, and nanofluid properties. Improved temperature uniformity, increased heat transfer, a bigger heat transfer surface, and the use of Taguchi orthogonal arrays to add randomization to the experiments—which leads to more reliable results—are possible advantages. Enhancing thermal performance in energy conversion systems and solar air heating, as well as advancing energy efficiency in a variety of industrial applications, are possible outcomes of this research.*

Key Words: **Double Helically coiled heat exchanger; Nanofluids; Hybrid nanofluid; CFD analysis, Heat transfer coefficient.**

1.INTRODUCTION

The incorporation of nanofluids into heat exchange systems is a viable avenue for improving heat transfer efficiency. This study does a thorough investigation, examining the effects of nanofluids on various systems, such as vehicle radiators, refrigerators, and central air conditioning. In particular, it explores the use of nanofluids in novel helical coil designs as well as conventional shell and tube heat exchangers.

This research practically models double helix coiled tube heat exchangers using computational fluid dynamics (CFD) and ANSYS software, correlating the results with empirical data. The implications of heat transfer rates, convective coefficients, and general thermal properties are carefully examined in relation to nanofluids, which act as the heat transfer medium.

This study systematically assesses the benefits of hybrid nanofluids in these heat exchange systems by using surfactants for stability and using design of experiments approaches, such as the L9 orthogonal array. The ultimate goal is to open doors for increased heat transfer rates, increased heat exchange surfaces, and improved temperature uniformity, which will raise thermal performance in a variety of energy conversion systems and industrial applications.

Through negotiating the complex interactions between design parameters, operational environment, and nanofluid dynamics, this study aims to promote improvements in thermal efficacy and energy efficiency in many industrial contexts.

2. LITERATURE SURVEY

M. Salem Ahmed et al. [1] The performance of a vapor compression refrigeration system using nanofluids (Al2O3, TiO2, and a hybrid of Al2O3/TiO2) in a chilled water air conditioning unit was experimentally investigated. The experimental results showed that the nanofluid with Al2O3/H2O had a higher coefficient of performance and a lower elapsed time for cooling the fluid compared to TiO2/H2O, with lower compression ratio and higher refrigeration effect. Experiments evaluated the performance of a chilled water air conditioning system using hybrid nanofluids with Al2O3 and TiO2 nanoparticles, which improved thermal conductivity and heat transfer potential. The coefficient of performance increased by 24.2% with the use of hybrid nanofluids compared to pure water, reducing the time to reach desired temperature. **Elsaid et. al. [2]** A study was conducted in Cairo, Egypt to optimize the design of vehicle radiators under hot arid climate conditions. Parameters such as nanoparticle concentrations, fluid type, and mass flow rate were examined. Cobalt oxide-based water showed higher thermal performance than alumina, with a higher performance index observed at lower concentration ratios and higher Reynolds numbers. The addition of EG decreased the Nusselt number and increased pumping power compared to pure water. **Gomaa et al. [3]** The study investigates the performance of a triple concentric-tube heat exchanger with rib inserts, finding that the insertion of ribs enhances convective heat transfer, with higher performance at higher rib pitch and lower rib height. Empirical expressions are predicted based on the obtained data. **Alimoradi et al [4]** The study investigates the exergy efficiency of forced convection heat transfer in shell and helically coiled tube heat exchangers, finding that efficiency decreases with increasing fluids temperature difference, and develops a correlation to predict efficiency based on various parameters, concluding that coils with more turns and smaller diameter are more efficient. **Alimoradi et al [5]** The study investigated the impact of operational and geometrical factors on the thermal effectiveness of shell and helically coiled tube heat exchangers, finding that the effectiveness is consistently 12.6% lower than parallel flow heat exchangers for the same conditions. **Alimoradi et al [6]** The study investigates the impact of various geometrical parameters on heat transfer and entropy generation in shell and helically coiled tube heat exchangers, identifying critical and optimal values to minimize and maximize the heat transfer rate per entropy generation. **Wang C et al [7]** The intelligent optimization design of a helically coiled tube heat exchanger is proposed, which increases heat flux and heat transfer rate by 110% and 101% respectively, and provides an automatic solution for optimizing various heat exchangers while considering pressure drop constraints. **Maghrabie et al [8]** Experimental study and sensitivity analysis conducted on a shell and helically coiled tube heat exchanger (SHCTHE) showed that the effectiveness of SHCTHE is higher in the vertical direction compared to the horizontal direction. Maintaining the SHCTHE in the vertical direction reduces the coil pressure drop compared to the horizontal direction. Changing the direction of SHCTHE from horizontal to vertical enhances the performance evaluation criteria (PEC). **Panahi d et al [9]** The present study investigates the use of a helical wire turbulator inside a shell and coiled tube heat exchanger. The fabrication method of the helically coiled tube with the turbulator and its effects on thermal and frictional characteristics are discussed. Experiments were conducted with water and air as the fluid in the coiled tube, both with and without the turbulator. The results showed that the turbulator significantly increased the overall heat transfer coefficient and pressure drop. Various parameters such as heat transfer coefficient, pressure drop, effectiveness, and NTU were evaluated and discussed. **Raghulnath et al [10]** The performance of a heat exchanger is evaluated based on various factors such as heat transfer coefficients, Reynolds number, Nusselt number, temperature distribution, residence time, and pressure drop. The use of helical coils and turbulators can improve the heat transfer coefficient and increase turbulence in the fluid flow, resulting in better performance. However, increasing the mass flow rate of the cold fluid above the hot fluid can decrease the overall performance of the heat exchanger. **Tuncer et al [11]** Shell and helically coiled tube heat exchangers are commonly used in various applications such as refrigeration, heat recovery, and chemical processing. Enhancing the effectiveness of heat exchangers can improve the overall efficiency of energy conversion systems. A new modification involving the integration of a hollow tube into the shell side of the heat exchanger has been proposed to regulate fluid flow and improve thermal energy transfer. Numerical simulation and experimental analysis showed successful design and performance of the modified heat exchanger, with heat transfer coefficients ranging from 1600-3150 W/m2 K on the shell side and 5700-13,400 W/m2 K on the coil side. **Rahimi et al [12]** The experimental investigation of a shell and tube heat storage unit (HSU) with a spiral tube filled with phase change material (PCM) shows that increasing the Stefan number accelerates the melting process and decreases the total melting time, while increasing the coil diameter decreases the total melting time and increases the final average temperature of the PCM, as well as the absorbed energy by the PCM. **Kumar et al [13]** The paper examines the effectiveness and energy actions of Shell and Coil heat exchangers in industries, specifically focusing on three different coil configurations and their flow attributes. The study uses Ansys Fluent software to simulate different working operations and concludes that the shell-helical coil heat exchanger arrangement is the preferred option, while the slinky coil can be used for enhanced heat transfer conditions if total pressure drop is not a performance measuring parameter. **Elsaid et al [14]** The study investigates the heat and flow characteristics of hybrid and single nanoparticles-based water passing through a triple ribbed tube heat exchanger (TRTHE). Computational fluid dynamics (CFD) modeling is used to analyze the system, and the results are validated with experimental data and empirical correlations. The findings show that the hybrid nanofluid of $Al2O3+MWCNT/H2O$ has a higher heat transfer rate compared to single nanofluids, and a lower rib louver width with semi-circular rib geometry improves the Nusselt number and effectiveness of the TRTHE. **Abdelaziz et al [15]** The paper examines the effectiveness and energy actions of Shell and Coil heat exchangers in industries, specifically focusing on three different coil configurations and their flow attributes. The study uses Ansys Fluent software to simulate different working operations and concludes that the shell-helical coil heat exchanger arrangement is the preferred option, while the slinky coil can be used for enhanced heat transfer conditions if total pressure drop is not a performance measuring parameter.

2.1 Summary of Literature Survey

The collection of studies investigates various aspects of heat exchangers' performance and optimization. Experimental analyses and simulations explore factors such as nanoparticle-enhanced fluids, geometric modifications, and turbulators within different types of heat exchangers. Findings reveal improved thermal performance, efficiency enhancements, and optimal configurations for diverse industrial applications.

2.2 Problem Identification

Use of helical coil in the shell and tube heat exchanger or double tube heat exchanger involves very thin elements and manufacturing and designing of thin elements required lot of precision. Instead of using helical coil inside a heat exchanger, we can use double helical coiled tube heat exchanger. It makes the flow more turbulent, which further increases the heat transfer rate and convective heat transfer coefficient.

In the present article, we can add up design of experiment and ANOVA techniques for the verification and optimization of the data.

Use of hybrid nanofluid, for more enhancement

3. ORTHOGONAL ARRAY

An orthogonal array is a mathematical construct used in experimental design to efficiently test the effect of multiple factors on a system. It's a structured matrix that helps in planning experiments by systematically varying factors across different levels to study their impact on the output or response variable. Orthogonal arrays ensure a balanced and efficient way of examining combinations of factors, reducing the number of experimental runs needed while still capturing essential interactions between variables.

1. Factors: These are the variables or inputs that researchers manipulate or control in an experiment to observe their effect on the outcome or response variable. Factors can be things like temperature, time, dosage, or any other variable that may influence the system being studied.

2. Levels: Each factor can have different settings or values called levels. These levels represent the specific variations or different conditions at which the factor is set during the experiment. For example, if the factor is temperature, the levels could be low, medium, and high temperatures.

4. METHODOLOGY

1. A doubly helical coiled tube heat exchanger is virtually designed in ANSYS software, 2022 version. The dimensions of the heat exchanger are as per the experimental base paper.

2. The inner tube has an inner diameter of 5.5 mm and outer diameter of 6.5 mm, whereas the shell is made of inner diameter of 11mm.

3. The material used for both the tubes are copper with its standard properties at given temperature. The inlet temperature of cold fluid is kept at 303K and inlet temperature of hot fluid is kept at 343K. The mass flow rate of hot fluid flowing through the annuus of both the tubes is kept constant at a value of 0.35kg/s, whereas the mass flow rate of cold fluid flowing through the annulus is varied from 0.40kg/s, 0.45kg/s, 0.50kg/s, and 0.55kg/s respectively.

4. The initial readings of this virtual model is validated with experimental results of our base paper. The water-water heat exchanger results are calculated, and data is presented for heat transfer rate, effectiveness, and LMTD values.

5. A Nano-Fluid is defined in virtual software whose properties are calculated based on standard formulas as mentioned ahead. The cold water flowing through annulus is replaced by this nano fluid while keeping the inlet temperature and its mass flow rate same. The calculations are found for this arrangement as well. Also, the nano fluid is checked for various values of volume fraction, and the best suitable volume fraction is used for the calculations.

6. The results are compared on the basis of heat transfer rate, LMTD, overall heat transfer coefficient and effectiveness of heat exchanger.

7. All the inlet conditions were taken according to literature survey.

8. The volume fraction for the nanofluid was taken as 0.75 %.

9. Surfactant was added for the stability of the nano fluid.

10. Number of experiments was decided by the L9 orthogonal array using design of experiment.

11. Factors are Mass Flow rate of Cold Fluid, Mass Flow rate of Hot Fluid, Cold Fluid Inlet temperature, and Cold Fluid Inlet temperature.

12. Response are Convective heat transfer coefficient, and rate of heat transfer

Table 1: Factors And Levels

Factors	**Levels**		
	1	**2**	**3**
Mass Flow rate of Cold Fluid	0.5	0.55	0.6
Mass Flow rate of Hot Fluid	0.35	0.4	0.45
Cold Fluid Inlet temperature	300	303	306
Hot Fluid Inlet temperature	353	347	343

Table 2: Specifications of Heat Exchanger

Sr. No.	**Parameter**	**Value in mm**	**Value in meters**
1	Inside Diameter of Copper tube	5.5 mm	0.055 m
2	Outside Diameter of Copper tube	6.5mm	0.065 m
3	Outside Diameter of Copper shell	11 mm	0.011 m
5	Effective Length of Copper tube	1000mm	1 m
6	Sweep	10, 20, 30	-

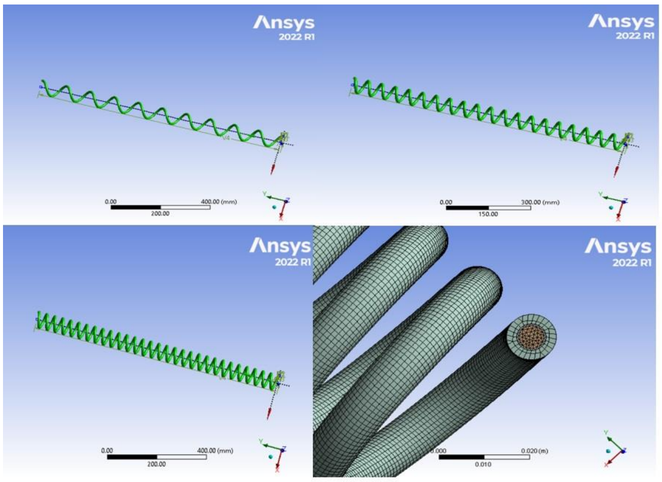

Figure 1: Geometry of Heat Exchanger with 10, 20 and 30 sweep with Meshing

Table 3: L9 Orthogonal Array

Experiment No	Column			
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

5. RESULTS AND DISCUSSION

Table 4 shows the maximum heat transfer rate of cold fluid for water-water and water-nanofluid with the sweep 10, 20 and 30. It is a comparison table. It clearly shows the rate of heat transfer is increasing as the number of sweeps increases. Also, rate of heat transfer is more in the case of nanofluid due to high thermal properties of nanofluid.

Table 4: Maximum Heat Transfer Rate of Cold Fluid

S.No	Sweep	Maximum Heat transfer Rate Water-Water (Cold Fluid)	Maximum Heat transfer Rate Water-Nanofluid (Cold Fluid)
1	10	5123.65	8564.89
2	20	5469.87	8896.24
3	30	6400.23	9459.82

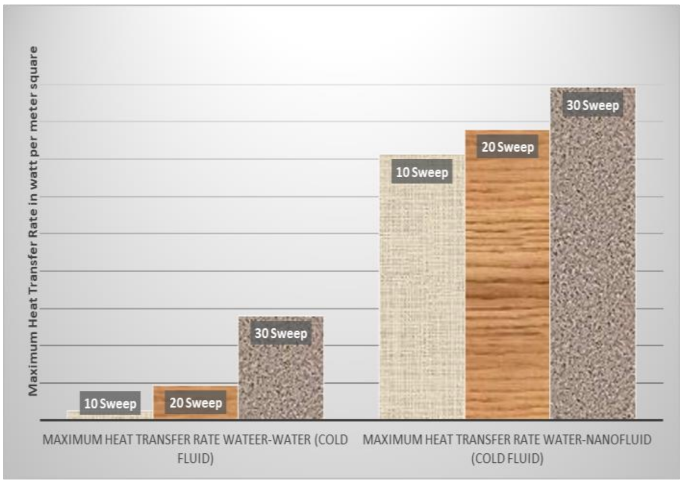

Figure 2: Graphical representation of Maximum Heat Transfer Rate of cold fluid for 10 sweeps, 20 sweep and 30 sweep

Table 5 shows the maximum heat transfer rate of hot fluid for water-water and water-nanofluid with the sweep 10, 20 and 30. It is a comparison table. It clearly shows the rate of heat transfer is increasing as the number of sweeps increases. Also, rate of heat transfer is more in the case of nanofluid due to high thermal properties of nanofluid.

Table 5: Maximum Heat Transfer Rate of Hot Fluid

S.No	Sweep	Maximum Heat transfer Rate Water-Water (Hot Fluid)	Maximum Heat transfer Rate Water-Nanofluid (Ho Fluid)
1	10	4896.58	8897.36
2	20	4756.23	9012.25
3	30	5687.23	9578.21

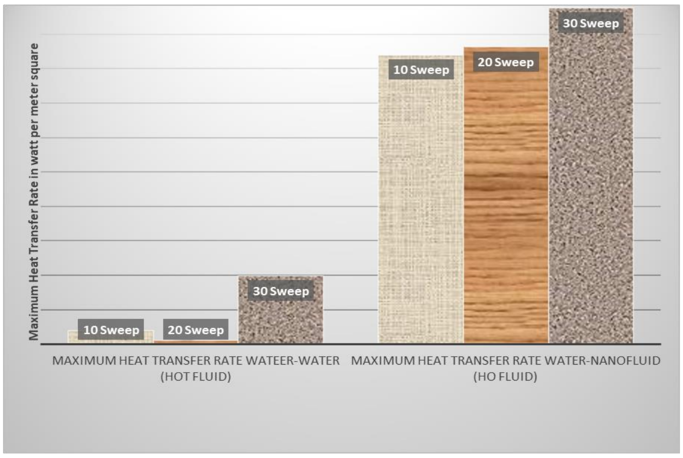

Figure 3: Graphical representation of Maximum Heat Transfer 0Rate of Hot fluid for 10 sweeps, 20 sweep and 30 sweep

Table 6: Convective Heat Transfer Coefficient of Cold Fluid

S.No	Sweep	Maximum convective heat transfer coefficient Water-Water (Cold Fluid)	Maximum convective heat transfer coefficient Water-Nanofluid (Cold Fluid)
1	10	863.23	1259.82
2	20	987.65	1878.96
3	30	1154.27	2016.26

Table 6 shows the maximum convective heat transfer coefficient of cold fluid for water-water and water-nanofluid with the sweep 10, 20 and 30. It is a comparison table. It clearly shows the convective heat transfer coefficient is increasing as the number of sweeps increases. Also, convective heat transfer coefficient is more in the case of nanofluid due to high thermal properties of nanofluid. convective heat transfer coefficient depends on the turbulency of the fluid. Coild increases the turbulency, hence the convective heat transfer coefficient.

Figure 4: Graphical representation of Maximum Convective Heat Transfer coefficient of cold fluid for 10 sweeps, 20 sweep and 30 sweep

Table 7: Convective Heat Transfer Coefficient of Hot Fluid

S.No	Sweep	Maximum convective heat transfer coefficient Water-Water (Hot Fluid)	Maximum convective heat transfer coefficient Water-Nanofluid (Hot Fluid)
1	10	598.23	637.54
2	20	689.63	1125.24
3	30	1298.62	1368.24

Table 7 shows the maximum convective heat transfer coefficient of hot fluid for water-water and water-nanofluid with the sweep 10, 20 and 30. It is a comparison table. It clearly shows the convective heat transfer coefficient is increasing as the number of sweeps increases. Also, convective heat transfer coefficient is more in the case of nanofluid due to high thermal properties of nanofluid. convective heat transfer coefficient depends on the turbulency of the fluid. Coild increases the turbulency, hence the convective heat transfer coefficient.

Figure 5 Graphical representation of Maximum Convective Heat Transfer coefficient of hot fluid for 10 sweeps, 20 sweep and 30 sweep

Table 8: LMTD Comparison

S.No	Sweep	Maximum LMTD Water-Water	Maximum LMTD Water-Nanofluid
1	10	47.6	49.2
2	20	48.7	50.2
3	30	49.3	50.9

Table 8 shows the comparison of LMTD for the water-water and water-nanofluid with the sweep 10, 20, and 30. As the sweep increases, LMTD also increases. Reason is the more heat transfer between the fluid which directly increases the temperature difference. Also, in the case of nanofluid, value is high, due to the same reason. Combined effect of nanofluid and more sweep coil gives maximum LMTD which is 50.9.

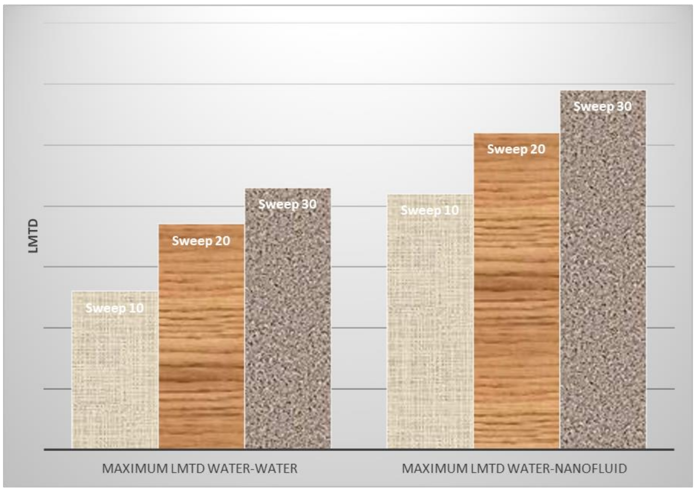

Figure 6: Graphical representation of LMTD for 10 sweeps, 20 sweep and 30 sweep

Table 9: Effectiveness Comparison

S.No	Sweep	Maximum Effectiveness Water-Water	Maximum Effectiveness Water-Nanofluid
1	10	0.095	0.109
2	20	0.102	0.177
3	30	0.177	0.209

Table 9 shows the variation of effectiveness for the case of water -water and water-nanofluid with the sweeps 10, 20 and 30. It can be clearly seen from the table 9 and figure 7, that the effectiveness increases with the number of sweep and with the use of nanofluid.

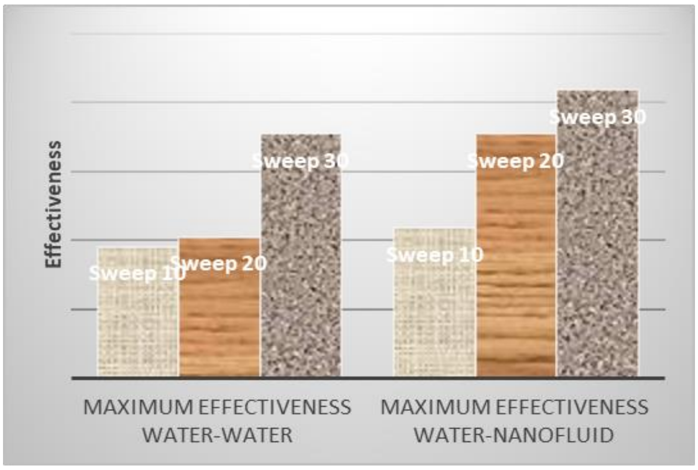

Figure 7: Graphical representation of effectiveness for 10 sweeps, 20 sweep and 30 sweep

6.CONCLUSION

A doubly helical coiled heat exchanger employing a hybrid nanofluid offers potential benefits. Nanoparticles in the fluid enhance thermal conductivity, boosting heat transfer. The unique coil design amplifies the surface area for efficient heat exchange. Utilizing Taguchi's Orthogonal array induces experimental randomness, ensuring reliable outcomes and promoting temperature uniformity through increased fluid mixing and turbulence.

Nanofluid gives more heat transfer rate and convective heat transfer coefficient than water-water heat exchanger due to enhanced thermal properties of nonfluid. Nanofluid with helical coil having 30 sweep gives best thermal properties and effectiveness due to turbulency created by the helical coil.

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