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Research Article

Assessing the Effect of Sediment Deposits on the Performance of Residential Heating Radiators: An Experimental Investigation

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ABSTRACT

In this investigation, we present pioneering findings on the detrimental effects of sediment deposits on the thermal and hydraulic performance of residential heating radiators through a novel experimental framework. Our approach, through the systematic introduction of particulate matter into the water circuit, quantifies the real-world impact of sediment accumulation. This methodology fills a significant void in literature with validated experimental data and establishes a method for assessing radiator performance under fouled conditions, adhering to ISO 3148 standards. The experimental results underscore a significant efficiency downturn: sediment presence increased pressure drop by up to 10.5% and reduced surface temperature by as much as 13%. Notably, heat output initially saw a slight increase, only to decrease by up to 28.5% over time, with these effects amplifying at higher inlet temperatures. These findings underscore the urgent need for tailored maintenance strategies to combat sediment-related degradation, offering invaluable insights for the design, maintenance, and optimization of heating systems beneficial to both industry stakeholders and end-users.

1. Introduction

Radiators, which utilize convection to distribute warmth from their surfaces to the surrounding air, are one of the primary and most effective methods for heating homes, workplaces, and public spaces. They are still fascinating due to their simplicity and ability to heat an area equally and effectively.

Extensive research has been conducted to investigate the performance of radiators and the parameters affecting various conditions; under an experimental Turkish environment, Tamer et al. [1] studied the heat performance of a panel radiator at various heating water mass flow rates, water inlet temperatures, and radiator inlet and outlet connection positions. They found that the heat output was almost linearly increased with increasing temperature, and higher temperature differences could be achieved for lower mass flow rates.

Based on the results of laboratory tests, Zhong et al. [2] evaluated how well radiators heated rooms at low temperatures. They compared the heat output at various excess temperatures to the heat output under ideal conditions, examining a variety of typical radiator types. For their simulations, they utilized the TRNSYS computing

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platform. Cholewa et al. [3] focused on the equivalence of the total heat transfer coefficient of a panel heating surface and the contribution of radiation and convection to the total heat exchange between the radiator surface and its surroundings. They analyzed characteristic parameters affecting the total heat flux mass transmitted from the heat exchange surface of a panel radiator. Teskeredzic and Blazeric [4] provided a mathematical model and a numerical solution algorithm for radiator heating of an ideal room, developing a modified transient heat conduction equation to address heat transfer at multi-layer exterior walls and room assembly. Their findings indicated that the associated heat flux could exceed the heat flux transmitted through windows or external walls for minor temperature differences between the interior walls and the surrounding air. Erdogmus [5] conducted experimental studies in a standard test room for his PhD thesis to determine the heat output of radiators. He also assessed the heat dissipation capabilities of three distinct panel radiators using numerical methods. Myhren and Holmberg [6] presented the results of performance testing on various ventilation radiator models in a controlled lab environment, verifying their findings through computational fluid dynamics (CFD) and identifying areas for potential system performance improvements. They considered the comfort and health implications of ventilation rates, air temperatures, and heat transfer through internal convection fins. Rahmati and Gheibi [7] examined heat transmission in certain radiators both experimentally and numerically to enhance the heat output of specific radiator types. Using standard BS EN 442 for their experiments, they compared the results with CFD findings, discovering that the modified radiator's heat output increased by approximately 45% compared to the original model. Tamer Calisir and his team investigated the effects of convector sheet thickness, spacing, convector height, convector tip radius, and convector trapezoidal height on a Panel-Convector-Convector-Panel (PCCP) radiator using both numerical and experimental methods [8]. Their research showed that radiator convection fins significantly influence both the total weight and heat output and that the convector tip radius enhances heat transfer while reducing the radiator's overall weight.

Water contains natural minerals and external deposition that flow into the radiator. When the water is heated, these particles will be deposited at the bottom of the radiator. Sediments will act as a barrier to letting heat pass through easily, besides causing corrosion of the inside surface of the radiator. So, investigation of its effect on malfunction of the radiator and reduces its lifespan is important. Many types of research have been done to investigate the effect of fouling on heat exchangers:

Zhenha et al. [9] conducted experiments to study how calcium carbonate builds up on surfaces during heat transfer. They looked at how different factors, like water hardness, flow speed, temperature, and alkalinity, affect this process. They used special equipment to monitor the buildup. Their findings demonstrated that as solution temperature and heat transfer surface temperature increased, the fouling rate and asymptotic fouling resistance increased along with falling fluid velocity, raising hardness and alkalinity and decreasing fluid velocity. Sulaiman et al. [10] looked into how fouling affected the efficiency of the shell and tube heat exchanger unit at a CO2 fertilizer-producing factory in Nigeria. They examined several energy equations written in MATLAB to calculate the overall heat transfer coefficients, capacity ratios, heat duties, and effectiveness. They found that, on average, the deviation of the overall heat transfer coefficient, effectiveness, and heat duty from the design values was over 15%, and the fouling factor was higher than the design value, which hurt the performance parameters of the heat exchangers. Barrow and Sherwin's theoretical study on tube and fin heat exchangers showed that fouling initially increases the heat transfer rate until it peaks and then decreases as blockages become more severe [11]. Recent advancements in thermal management systems have highlighted the efficacy of the presence of particles in enhancing heat transfer capabilities within microchannel heat sinks. Studies, such as the one conducted by Khodabandeh et al. [12], have explored novel designs incorporating double-layer microchannels with sinusoidal cavities and rectangular ribs, utilizing water nano-fluid/GNP–SDBS mixtures. This research demonstrated a significant improvement in thermal performance, attributed to better fluid mixing and increased heat transfer efficiency. Such innovations are crucial in addressing challenges posed by sediment deposits. A notable study by Arasteh et al. [13] underscores the potential of using metal foam in the divergent sections of sinusoidal parallel-plate heat exchangers, revealing a significant uplift in thermal performance. This enhancement, rooted in the superior fluid dynamics and heat distribution characteristics of metal foams, presents a compelling avenue for mitigating the impact of sediment deposits on radiator efficiency. Our investigation draws inspiration from such advancements, exploring the interplay between sediment accumulation and heat transfer processes in residential radiators.

The study on adding SiO2 nanoparticles to oil by Mohammad Hemmat Esfe et al. [14] reveals that particle concentration and temperature significantly affect fluid viscosity, which is crucial for thermal system performance. It confirms that the presence of additional particles can change thermal management.

Addressing the challenge of sedimentation in heat exchangers, Abu Zaid [15] pioneered a method to measure its extent in tube heat exchangers. His findings revealed a dual aspect of increased surface temperature: an initial acceleration in sediment formation leading to enhanced thermal efficiency, which subsequently diminishes due to the accumulation of thicker sediment layers. For cooling tower applications, Cremaschi et al. [16] reported experimental data on the waterside fouling performance of Brazed-Plate Heat Exchangers (BPHE) utilized in direct refrigerant-to-water condensers. They observed that the fouling of the plates had a considerable impact on the waterside pressure drop, which was between 10% and 11 times greater than the corresponding waterside pressure drop in pristine conditions. Awad [17] created a theoretical methodology to look into how surface temperature affects surface particle fouling. Because of his research, a critical surface temperature was established for each working condition. When the working temperature is lower than the critical one, the fouling rate will rise as the surface temperature goes up, reaching its highest value closest to the critical temperature. On the other hand, some erosion of the heat transfer surface will happen when the working temperature increases to a level over the critical one. He concluded that depending on whether the working temperature is under, same to, or higher than the critical surface temperature, a rise in surface temperature may result in a reduction, a jump, or have no impact on the amount of materials depositing at the surface. Zhiming Xu and colleagues [18] presented a numerical simulation study on the parameters of particles fouling on the floor heat transfer surface in a rectangular duct. They concluded that this fall is caused by an increase in the inlet velocity and a decrease in the concentration after examining the effects of inlet velocity, concentration, wall temperature, and particle diameter on the asymptotic total fouling mass of the fly ash particles. Long-term research on the impact of flow velocity on calcium carbonate fouling in a twin-pipe heat exchanger was conducted by Liang-Chen Wang et al. [19]. Their findings suggest that fouling affects fluid flow and heat exchanger thermal efficiency in two ways during the induction phase: first, by increasing surface roughness, and then, as fouling spreads, by decreasing the metallic surface area of the test tube. The production of deposits may be influenced by molecular transport in laminar flow or transitional flow when the fouling rate rises sharply with velocity. Nevertheless, the flow velocity in a turbulent flow has less impact on the fouling rate.

The most common scale farmers in home heating systems, aluminum oxide, ferric oxide, and clay, become settled by their weight. This property causes scale formation in the most sensitive area, particularly in the radiator (Fig.1). The main issue brought on by fouling is connected to how significantly it affects the thermal and hydraulic performance of the radiators when fouling deposits build up, such as increasing energy consumption and decreasing efficiency and heating capacity. While it is standard practice to use water softeners in heating systems to prevent sediment deposits, our research focuses on scenarios where such preventative measures might not be effectively implemented or are absent.

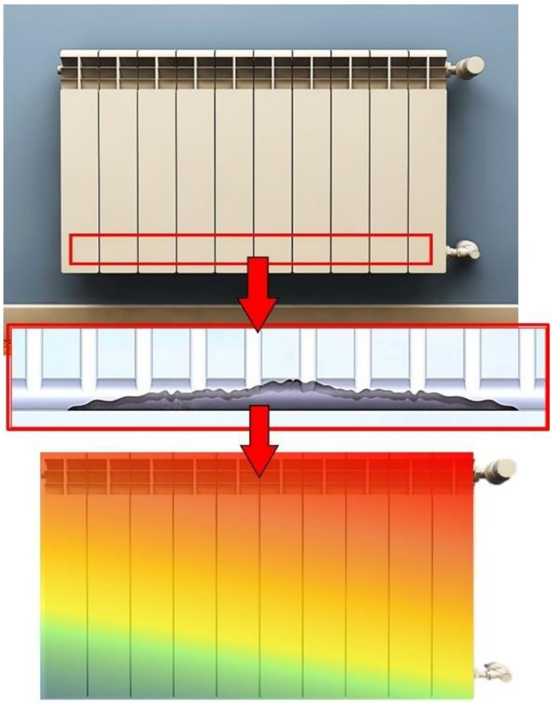


Fig. 1. View of the radiator and the points exposed to sediment

The objective is to understand the impact of sediment deposits on the performance of heating radiators over time, particularly in regions with hard water or older systems where maintenance practices may not align with modern standards. We present novel insights into the impact of sediment deposits on the thermal and hydraulic performance of residential heating radiators. Unlike previous research that primarily focuses on theoretical analysis or simulation of fouling effects, our work employs an experimental approach to quantify the impact of real-world sediment accumulation. By systematically introducing controlled quantities of particulate matter into the water circuit and monitoring the radiator's performance over time, we provide empirical evidence on how sediment deposits degrade the efficiency of heating systems. This contribution not only fills a gap in the existing literature by offering validated experimental data but also proposes a methodological framework for assessing radiator performance under fouled conditions aligned with ISO 3148 standards. Our findings have significant implications for the design, maintenance, and optimization of residential heating systems, offering valuable insights for both manufacturers and end-users.

2. Experimental Methods

2.1. Test - Bench Design (Room Design)

Radiators are heating bodies that emit heat primarily through natural convection [19]. There are several standards for measuring the thermal specification of radiators, such as EN 442, BS 3528, ISO 3147, ISO 3148, ISO 3150, and DIN 4722. The ISO 3148 International Standard specifies a method for the determination of the thermal output of radiators, convectors, and similar appliances, using an air-cooled closed booth.

To follow this standard, a test booth measuring 4 × 3.5 × 2.7 m^3 was set up, and the walls, ceiling, and floor were insulated with materials having an average thermal conductivity of 0.04 ($W/m^2.K$), as depicted in Figure 2. During the test, the booth's surface temperature was maintained constant by a cold air supply. To ensure the stability of the booth temperature, 21 thermocouples were strategically placed, as prescribed by the standard. The locations and specifications of the thermocouples are detailed in Table 1.

Fig. 2. Isolated test booth

Table 1. Place of thermocouple installation in the booth [20]

Zone	Description	Points	Position
Air Temperature	On the vertical axis of the inner enclosure	Reference point	0.75 (m) from the floor
		4 points	0.05 (m) from the floor 0.50 (m) from the floor 1.50 (m) from the floor 0.05 (m) from the ceiling
	On four verticals at 1(m) from each of the two adjoining walls	8 points (2 on each vertical)	0.75 (m) from the floor 1.50 (m) from the floor
Internal faces of inner enclosure	Central points	6 points	At the centers of the six inner faces of the enclosure
	On center lines	2 points	On the vertical center line of the inner faces of the wall against which the appliances under test are placed; 0.3 (m) from the floor

2.2. Control of Ambient Conditions in the Inner Enclosure and Steady-State Conditions

The air temperature measured at the reference point was maintained within ±0.1 °C, settling at a value of 20 °C. Steady-state conditions were established when the values of the parameters measured at no fewer than six equal intervals during the test did not exceed the limits specified in ISO 3147.

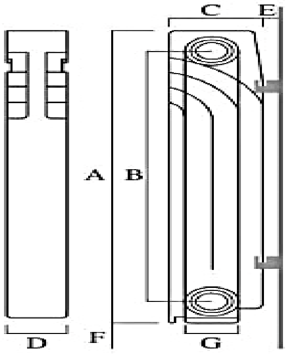
2.3. Heat Exchanger

This study aims to characterize the behavior of heat exchangers that are used as a home application radiator under the condition of fouling. The working fluid that flows in the heating system of the house comprises particles from the central heating system, sludge, or minerals that could settle in pipes and especially in home heating radiators due to the low velocity of the working liquid. Fouling in the home heating radiators may cause non-uniform heat release. Particles could block the flow of water through the lower collector, and the radiator would be cold at the bottom and hot at the top. So, regular cleaning is essential to keep the radiators in good working condition.

In this paper, the ten-blade radiator model -TERMOCALOR 500 IRAN RADIATOR- was used as a case study. The dimensions of the radiator are illustrated in Figure 3.

2.4. Set-up

To compare the effect of fouling on the performance of the heat exchanger with that of a clean one, two highly similar test sections were utilized; one operated with fluid containing particles, and the other used clear water [21]. Both systems were installed in the same insulated booth separately and operated under identical ambient conditions. A schematic diagram of the experimental setup is presented in Figure 4.



A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)
580	500	90	61	25	120	25.4

Fig. 3. Dimension of the examined radiator -THERMOCALOR 500-

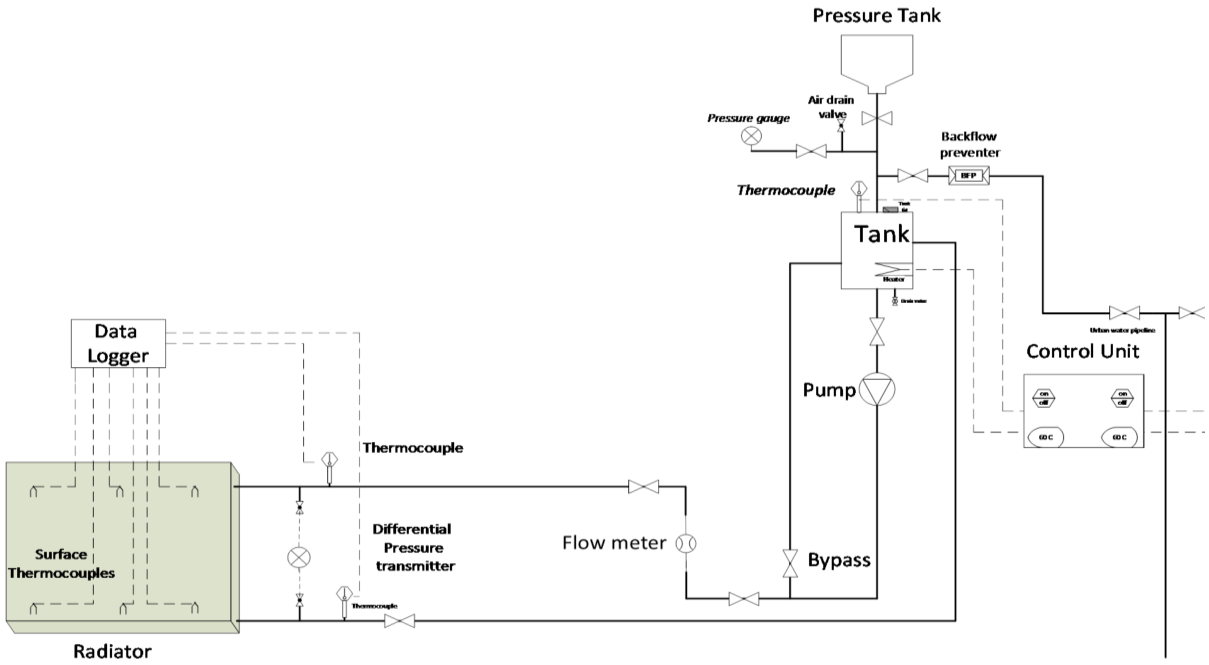


Fig. 4. Schematic diagram of the experimental system

Flowing water, fouled by the addition of scale and heated by a 2000 W electrical heater in the pressurized reservoir, was circulated through the tubes by a circulating pump. A PID control system regulated the fluid temperature in three stages, and the system's pressure was maintained at 1.5 bar using a pressure tank. The fluid flow rate was controlled with a flow meter and a control valve. The inlet and outlet temperatures were measured with K-type thermocouples placed as close as possible to the heat exchanger, and a 3051 Rosemount pressure differential transmitter was utilized for measuring the pressure drop between the inlet and outlet of the radiator. The surroundings of all tubes and tanks were insulated. Six K-type thermocouples were attached to the outer surface of each radiator to measure the average surface temperature. Figure 5 illustrates one of these radiators and its attachments.

Table 2 presents details on the flow characteristics at various inlet fluid temperatures, providing a comprehensive overview of the mass flow rate and additional vital parameters, facilitating a detailed understanding of the operational conditions in which the experiments took place.

Fig. 5. The radiator and connections

Table 2. Flow characteristics at various inlet fluid temperatures

Q [lit/hr]	T [C]	D [m]	ρ [kg/m^3]	μ [kg.m^{-1}.s^{-1}]	U [m/s]	Re
13.2	45	0.0224	990.2	0.000596	0.009305	**346.2**
25.8	60	0.0224	983.13	0.000466	0.018186	**859.4**
40.2	75	0.0224	974.79	0.000375	0.028337	**1649.9**

2.5. Uncertainty Analysis

As a result, they ensure the quality of the test and its outcomes. The uncertainty of calculated results can be determined with good accuracy by using the square root of the effect of each of the inputs. The Kline and McClintock correlation [22] is utilized to calculate the uncertainty of heat output, as outlined in Equation 1.

$$\delta R = \left\{ \left(\sum_{i=1}^{N} \frac{\partial R}{\partial X_i} \delta X_i \right)^2 \right\}^{1/2} \quad (1)$$

where δX_i is the uncertainty of each of the independent parameters, and N is the total number of variables. The relative uncertainty $(\delta R/R)$ of heat output is calculated as 4.38%.

2.6. System Validation and Reliability

According to standards such as BS 3528, ISO 3146, 3147, 3150, or DIN 4722, a radiator's nominal heat output is determined by setting the input temperature at 90 °C and adjusting the mass flow rate until the output temperature reaches 70 °C, with a room temperature set at 20 °C. These circumstances are referred to as the typical circumstances [23]. For conditions deviating from this, correction factors are required, which are provided by the manufacturer specific to the radiator model. The Iran Radiator company, which manufactured the radiator used in this study, declared the heat output capacity under standard conditions, as calculated according to ISO 3147-3150, and introduced the following equation for other conditions:

$$Q = Q_n \left(\frac{\Delta T}{60} \right)^{\eta} \quad (2)$$

The values of Qn=146 (W) for each blade and η=1.317 resulted from the product's catalog. In addition, there are also comprehensive correction factors from experimental research that can be used for any radiator model, depending on the radiator connection. Over a range of temperature differences and flow rates, Schlapmann studied the heat output of various radiator types [23]. He concluded that by using the following correction factors, the output could be calculated for all radiators:

$$\frac{\dot{Q}}{\dot{Q}_0} = \phi \left(\frac{\Delta T_m}{\Delta T_{m0}} \right)^{n\,\psi} \quad (3)$$

$$\Delta T_m = \frac{1}{2}(T_{in} + T_{out}) - T_{room} \quad (4)$$

Standard test circumstances are indicated by subscript 0. The value of the exponent n is 1.3. The flow rate and connection style, but not the type of radiator, affect the correction factors ϕ

and ψ. To ensure the correct operation of the test booth and installed set-ups, the measured heat output of the radiators at three different inlet temperatures with three consecutive repetitions was compared with the forecast of the radiator manufacturer and Schlapmann approximation.

$$Q = \dot{m}C_p(T_{in} - T_{out}) \tag{5}$$

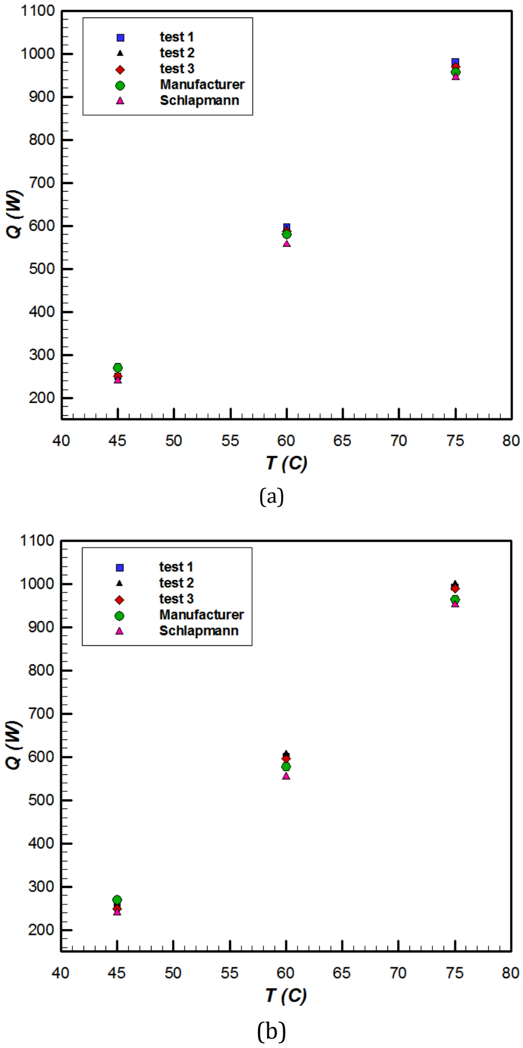
Figure 6 shows the performance of set-up 1 and set-up 2, which worked with pure water as the working fluid, and compares the difference between our experimental data with the data from existing correlations.

2.7. Particle Preparation as Fouling

Regarding the operational parameters, the sediment composition was determined through chemical analysis using the XRF method on real radiator samples, post-separation, and drying. Figure 7 illustrates the composition and percentage of various components, primarily consisting of aluminum oxide, with silicon dioxide (clay) and iron oxide as significant components. To ensure relevance and consistency, substances constituting less than 2 percent by weight were excluded from the sediment-forming fluid. For uniformity, particles of iron oxide, aluminum oxide, and clay were sifted through a 0.5-millimeter filter. Each component was then weighed in specified percentages (74% aluminum oxide, 15% iron oxide, and 11% clay) to create the final sediment blend.

To maintain consistency across tests, exactly 182 grams of dry particles were injected as sediment-forming agents in each experimental run, ensuring the comparative nature of our study and the accurate representation of sedimentation effects. The particles were first mixed with 2 liters of water to create a uniform sediment mixture. This mixture of water and particles was then added to the circulating water within the set-up at a specific time.

At the end of each test, the whole components of the set-up were separately cleaned and were ready for a new test.



(a)

(b)

Fig. 6. Validation of plain radiators according to existing correlations a) set-up 1, b) set-up 2

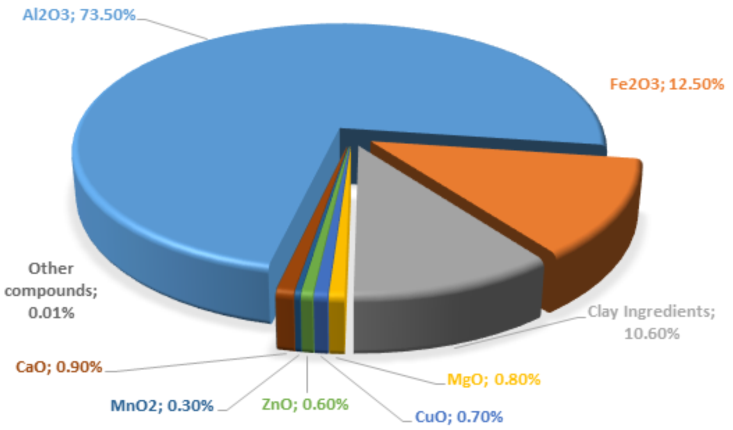


Fig. 7. XRF decomposition result of real fouling samples

3. Result and Discussion

This study investigated the thermal performance of home heating radiators affected by sediment deposits. We conducted experiments using two identical setups, one with sediments and one without, at three different inlet temperatures. At the beginning of the test, the flow rate was modified for each inlet temperature so that the variance between the inlet and outlet temperatures of the radiator ranged between 18 and 22 K [20]. During each test, fluid inlet temperature and room temperature were kept constant. On average, the complex of set-ups and test booth reached a steady-state after 3 hours, after which data recording was begun. Each test lasted 72 hours, with data being recorded every 30 minutes.

3.1. Heat Output

During the test time, the particles settled inside the radiator due to their high concentration and the force of gravity. The heat output of each radiator over time was determined separately by applying Equation 5. The variation of radiators' heat output versus time at various inlet temperatures is presented in Figure 8.

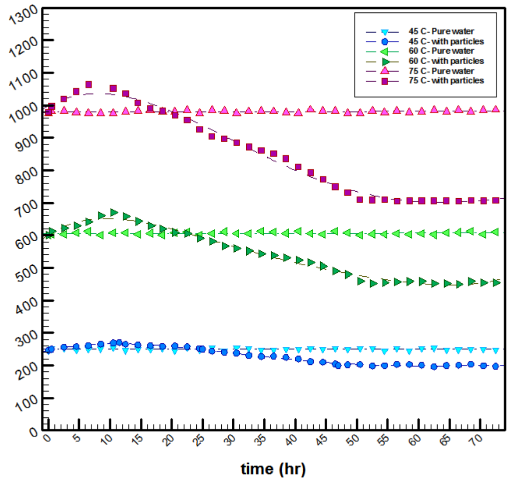


Fig. 8. Heat output versus time at various inlet temperatures

In the exploration of heat output variations due to sediment deposits within residential heating radiators, our findings illustrate a nuanced thermal response to particulate matter accumulation. Initially, the presence of metal oxide particles within the working fluid contributed to a modest enhancement in heat transfer efficiency. This initial increase is attributed to the elevated thermal conductivity and the induced turbulence by the particles, facilitating a more effective heat exchange with the environment.

However, as sedimentation progressed, a notable decline in heat output was observed, culminating in reductions of 23%, 26.82%, and 28.5% for inlet temperatures of 45°C, 60°C, and 75°C, respectively. This decline starkly illustrates the detrimental effects of sediment accumulation, overshadowing any initial benefits conferred by the enhanced thermal conductivity and turbulence. The reduction in heat output is particularly pronounced at higher inlet temperatures, indicating a temperature-dependent exacerbation of sedimentation impacts.

Comparatively, similar studies have reported varied impacts of particulate matter on heat transfer systems, yet few have delved into the dynamic progression of heat output over time with real-world sediment accumulation. For instance, the work by Khodabandeh et al. [13] highlights the initial enhancement of heat transfer in microchannel heat sinks with nano-fluids, a principle somewhat mirrored in our initial findings. Nonetheless, our study extends the narrative by illustrating the long-term detriments of sediment buildup, a critical aspect previously underexplored.

This discussion not only reaffirms the significance of our experimental approach but also illuminates the critical thresholds at which sediment accumulation begins to overwhelmingly negate any initial benefits to heat output. The implications of these findings are profound, suggesting that while minor sediment presence might not immediately impair system efficiency, proactive measures are necessary to prevent significant performance degradation over time.

Furthermore, our study invites a reevaluation of maintenance strategies for residential heating systems, emphasizing the need for periodic cleaning to mitigate the adverse effects of sediment accumulation.

3.2. Pressure Drop

Settled particles in heat exchangers cause some changes in the geometry of flow channels and affect the pressure drop. The fouling layer narrows the flow path by decreasing the inner diameter, thus causing an increase in the pressure drop. In this experiment, pressure drop was recorded every 30 minutes using a 3051 Rosemount pressure difference transmitter. Figure 9 demonstrates these changes concerning inlet temperature and time, which clearly illustrates that for the same concentration of particles at high inlet temperature, the pressure drop has the most changes. The rise in pressure drop at inlet temperatures of 45, 60, and 75 °C compared to the clean state is 6.51%, 8.64%, and 10.4%, respectively. This result could lead us to the concept that fouling deposition would be more significant at higher temperatures.

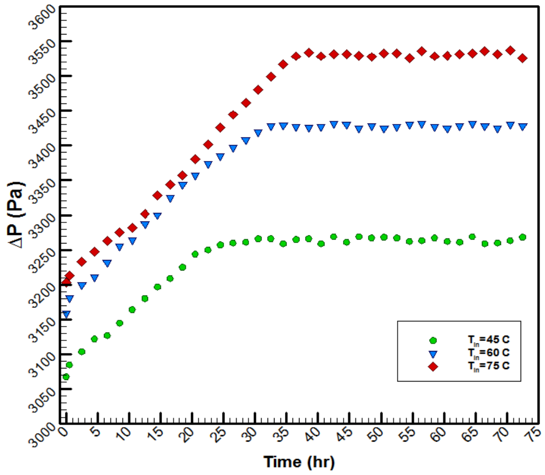
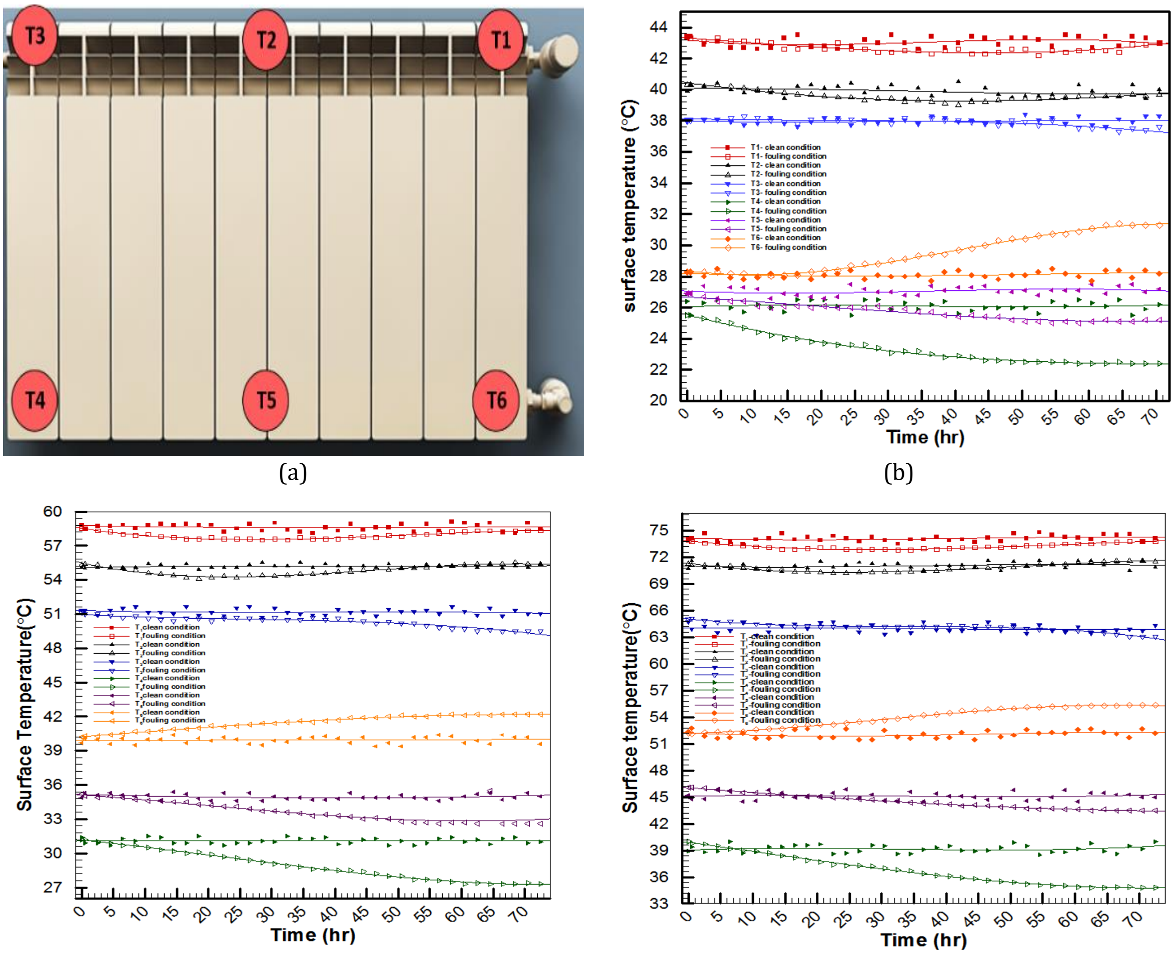


Fig. 9. Pressure drop versus time at various inlet temperature

3.3. Surface Temperature

The radiator surface temperature was measured at the 6 points shown in Figure 10 by K-type thermocouples. The surface temperature at these 6 different points during 72 hours, under both clean and fouled working fluid conditions at various inlet temperatures, are shown in Figure 10. In general, at all fluid inlet temperatures, there is a high-temperature gradient between the inlet range of the fluid flow to the radiator and the lower end of the radiator because of the differentiation of the mass flow rate in the vertical ducts. Initially, with the entry of sediment particles into the radiator, the amount of heat transfer to the environment was increased slightly due to the metallic nature of the particles. As time passes and the thickness of the sediment layer inside the radiator increases, the passage of the fluid to the lower end of the radiator narrows and the flow rate reduces, improving the temperature gradient at this point. This makes the fluid move straight from point 1 to point 6. This movement reduces the difference between the inlet and outlet temperature of the radiator and the overall heat output. With the appearance of the sediment layer inside the radiator, its surface temperature was decreased to a maximum of 12.1%, 12.5%, and 13% compared to the clean condition at inlet temperatures of 45, 60, and 75 °C, respectively, which shows incomplete movement of fluid in the radiator.



(a)

(b)

(c)

(d)

Fig. 10. a) Surface temperature measuring points, b) Surface temperature versus time at 45 °C, C) at 60 °C and d) at 75 °C

4. Conclusions

The effect of fouling on the performance parameters of a home heating radiator was confirmed experimentally using a standard testing room according to ISO 3148. The tests were carried out at three different inlet temperatures. The flow rate was adjusted to maintain a difference of 18 to 22 K between the input and output temperature of the flow at the beginning of the test. A specific quantity of particles was injected into the radiator and the heat output, pressure drop, and surface temperature were compared with the clean condition through 72 hours. The results of experiments indicate that heat output and surface temperature decreased by up to 28.5% and 13%, respectively, and pressure drop rose to 10.5%. These effects are intensified by increasing the temperature of the working fluid. As the particles entered the radiator, its end channels were blocked, resulting in reduced radiator thermal efficiency. Given the widespread use of radiators in homes and offices, it is important to find an active solution to remove sediment continuously.

In conclusion, our study provides critical insights into the effects of sediment deposits on the performance of residential heating radiators, offering significant contributions to both theoretical understanding and practical applications. The implications for manufacturers, maintenance professionals, and building managers are profound, guiding the design of more efficient heating systems, the optimization of maintenance protocols, and the enhancement of system longevity and energy efficiency. By addressing these practical considerations, our research paves the way for advancements in the heating industry that benefit both providers and end-users.

5. Future Perspectives

In looking ahead, our research opens several avenues for further investigation into the mitigation of sedimentation impacts on residential heating systems. Future studies could explore the efficacy of various anti-fouling materials and coatings to prevent sediment accumulation. Additionally, the development of more sophisticated sediment detection and removal technologies offers a promising area for innovation. Moreover, the amount of sediment and its thermal effects can inform the selection of a suitable turbulator to mitigate these effects, which can be explored in future papers. Another vital perspective involves the examination of sedimentation effects in a broader range of heating systems, including commercial and industrial applications, to fully understand the scalability of proposed solutions.

Nomenclature

C_p	Specific heat capacity (j/Kg.K)
$\dot{m}$	Mass flow rate (Kg/s)
n	Temperature different index (*dimensionless*)
$\dot{Q}$	Heat output rate (W)
T_{in}	Inlet temperature (°C)
T_{out}	Outlet temperature (°C)
T_{room}	Room temperature (°C)
η	Manufacturer temperature different index (*dimensionless*)
ΔT_m	Arithmetic mean temperature difference (K)
ψ	Temperature index correction factor (*dimensionless*)
ϕ	Radiator output correction factor (*dimensionless*)
δR	Uncertainty (*dimensionless*)

Subscripts

n	Catalog condition
0	Standard test Condition

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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