Form B: Full Proposal Template

(Submit final as a PDF described in **Full Proposal Preparation Instructions** above).

Form B: IGEM-HERC Full Proposal Cover Sheet

Idaho State Board of Education

PROPOSAL NUMBER: (to be assigned by HERC)	TOTAL AMOUNT REQUESTED: $125,000
Proposal Track (select one): ● Proof of Concept ● Initial Startup ● Commercialization	Proof of Concept

TITLE OF PROPOSED PROJECT:
Advanced Compact and Efficient Heat Exchanger Technology
SPECIFIC PROJECT FOCUS: This project will develop numerically and evaluate experimentally a new concept of compact Plate-Type Heat Exchanger with Oval-Twisted crossflow channels (PTOTHX). The compact size and improved heat transfer performance of this latest technology could be a game-changer for Idaho's energy economy. Its potential in various applications, including clean power production, HVAC, industrial process heat, distributed hydrogen production, and distributed ammonia production for fertilizer, could boost the energy sector, providing a solid foundation for the state's energy future.

PROJECT START DATE: 07/01/2025	PROJECT END DATE: 06/30/2026
NAME OF INSTITUTION: Idaho State University	DEPARTMENT: Nuclear Engineering

ADDRESS:	921 S. 8th Ave., Stop 8046 Pocatello, ID 83209-8046

E-MAIL ADDRESS: isuaor@isu.edu	PHONE NUMBER: 208-282-5824

NAME: Dave Harris	TITLE: Assistant VPR	SIGNATURE:

PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR	Amir Ali	Associate Professor	Amir Ali
CO-PRINCIPAL INVESTIGATOR			

NAME OF PARTNERING COMPANY: Idaho National Laboratory	COMPANY REPRESENTATIVE NAME: Dr. Ahmed Hamed
SIGNATURE:	

Authorized Organizational Representative	NAME: Dave Harris	SIGNATURE: Dave B. Harris

Advanced Compact Heat Exchanger Technology for Efficient Energy Utilization

Principal Investigator: Amir Ali[1,2]

Associate Professor, Nuclear Engineering Department, Idaho State University (ISU)

Innovation Laboratory Lead, Center for Advanced Energy Studies (CAES)

Budget Requested: $125,000 (Proof of concept, one year)

1. BACKGROUND & MOTIVATIONS

Heat Exchanger (HX) technology is crucial for energy efficiency in many engineering processes, allowing for the recovery and reuse of waste heat, reducing energy consumption, and promoting sustainability. This technology not only plays a vital role in improving safety and maintaining precise temperatures in various applications but also significantly enhances product quality across industries like chemical processing, power generation, and HVAC systems. With growing interest in clean energy applications, HX technology is becoming highly involved in hydrogen production and heat processes, biomass energy extraction, renewable energy (wind, solar, and geothermal) integration, and advanced nuclear power known as Gen IV reactors (Small and Micro reactors) [1]. Its role in promoting sustainability is a key driver for its increasing adoption.

The global HX market size was valued at $17.61 and $18.73 billion in 2023 and 2024, respectively. However, the most compelling aspect is the market's projected growth to $35.34 billion by 2032, exhibiting a compound annual growth rate (CAGR) of 8.26% during the forecast period. The HX market in the US is also set to grow significantly, reaching an estimated value of $4.61 billion by 2032. This growth, driven by the rising focus on energy efficiency and the low operating cost of energy systems, presents a promising investment opportunity. The business forecast indicates that the HX technology market is in high demand and promising for the next few years [2]. The market's major demanded features include high heat transfer efficiency, compactness, high resistance to fouling, and reduced pressure drop, all leading to extended lifetime and reduced operational and maintenance costs.

Novel HX designs implementing geometrical and surface modification combinations are expected to perform better than traditional HX technologies. Applied enhancement techniques seek to achieve (1) higher overall heat transfer performance, (2) increased compactness, and (3) simplified or comparable manufacturability. Plate-type HXs and Printed Circuit HXs (PCHXs) are compact designs that achieve high heat transfer rates per unit volume by utilizing several small channels, which maximizes the heat transfer surface area between the hot and cold fluids [5]. Advanced manufacturing technologies enable the manufacturing of HX units with complicated micro/nano size channel geometries to improve the performance of innovative HX technology.

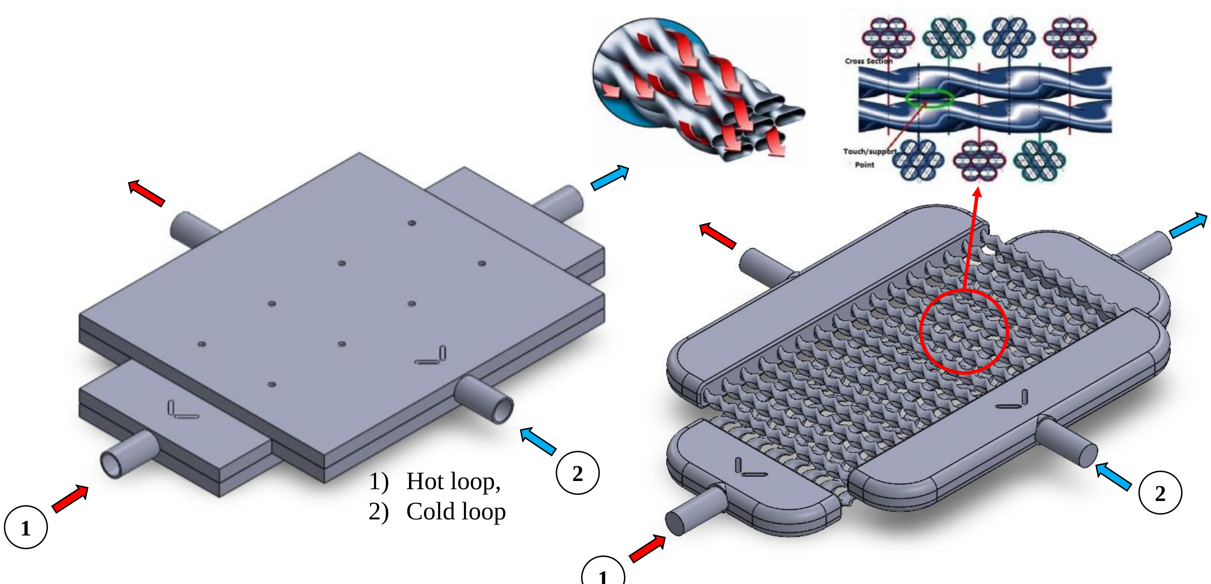
Developing a new HX technology concept that would improve one or more market setup characteristics beyond what is already available is an approach for a new startup business in Idaho to be part of a promising national and global business market. With its potential for innovation and growing energy sector, Idaho is well-positioned to make significant contributions to the HX technology market. The compact size and purportedly improved heat transfer performance of newly developed HX technology could be a game-changer for Idaho's energy economy. Its viability in various applications, including clean power production, HVAC, industrial process heat, distributed hydrogen production, and distributed ammonia production for fertilizer, could significantly boost the state's energy sector.

2. OBJECTIVES & SIGNIFICANCE

Plate-type HXs are compact and efficient designs that have been utilized for many decades in diverse applications. Further performance improvement and size reduction can be achieved using several small and complex geometrical channels. Currently, advanced manufacturing technologies enable the design and fabrication of compact-type units with complicated channel geometries to achieve the highest performance and meet the compact criteria of innovative HX technology. Over the last few years, the oval twisted tube geometry has shown highly improved performance in many HX design concepts, including straight oval-twisted shell and tube, oval-twisted spiral, and oval-twisted helical tube HX concepts, but not the compactness which is becoming a desirable condition in advanced HX technology [3-6].

The proposed HX design concept combines the compactness of plate-type HXs and twisted channels, which provide additional turbulence and flow swirl enhancement in addition to the compactness nature of the design (Figure 1). The new concept is expected to:

1. Enhance the fluid mixing and convection heat transport (high heat transfer efficiency).
2. Provides tube self-support when used in arrays (no tube supports or baffles).
3. Increase heat transfer per unit volume when tubes are in crossflow arrangement (increased compactness).
4. Minimize or eliminate stagnation points (low or less fouling).



(a) Unit overview **(b) Unit interior oval-twisted channels**

Fig. 1. New design geometric flow path (fluid regions) of PTOTHX.

The Plate concept's primary results (no design optimization) are auspicious compared to a similar concept utilizing circular tubes instead of oval-twisted tubes [7]. Further work is needed to complete the technology proof of concept (TRL1), which is the purpose of this proposal [7].

The plate-type oval-twisted HX (PTOTHX) potential size compactness, enhanced efficiency, and reduced fouling would reduce operational and maintenance costs. These characteristics would align the PTOTHX with the HX market requirements, support the application of intellectual properties for commercialization, and increase its competence with the existing HX technology. The new technology has endless energy applications that align with Idaho's HERC funding priorities.

The advanced HX technology, particularly the PTOTHX, is in high demand for many resident research and industrial businesses within Idaho (e.g., Idaho National Laboratory (INL), BWXT, Innovation System Laboratory (ISL), Boston Government Service (BGS), Walsh Engineering, and more). The PTOTHX has a high potential for obtaining intellectual property licenses and establishing research and business partnerships with many companies and research institutions to support many upcoming energy-related projects within the state in the coming years. This high demand strongly indicates the project's potential success and ability to impact the energy sector significantly.

3. PROJECT TASKS

This project aims to numerically optimize the design and experimentally test and evaluate the performance of a new concept of compact plate-type HX with oval-twisted crossflow channels. The plate-type oval-twisted HX (PTOTHX) is a crossflow configuration, with short channels on one side (for hot fluid) and long channels on the perpendicular side (for cold fluid) (Figure 1).

The project under the proof-of-concept stage has three essential tasks:

I. Task#1 - Design concept optimization (TRL1):

During this task, the geometrical parameters will be optimized to maximize the efficiency of the PTOTHX, including the number of channels, channel hydraulic diameter, channel twist pitch, and the oval cross-section aspect ratio. In addition to other available data for compact HXs technology in the literature, the project will establish a reference case, circular channels (PTCHX), for comparison with (PTOTHX).

Outcome:

(1) The best geometrical and operational parameters for maximum performance.

(2) Enable us to fabricate the least number of efficient prototypes to minimize budget expenses (Task#2).

(3) Supports the development of the experimental test matrix (Task#3)

II. Task#2 - Prototype formulation or fabrication (TRL2):

The optimized design will be fabricated using one of Idaho's advanced/additive manufacturing technologies. Multiple prototypes will be fabricated. During the fabrication time, all necessary facility modifications will be carried out to prepare for conducting experiments (Task#3)

Outcomes:

(1) A total of 3 optimized designs of the new HX, two units of twisted geometry to increase confidence in the results, and 1 unit with circular geometry to quantify the advantage over the currently existing technology in the market

III. Task#3 - Experimental validation (TRL3):

The fabricated model will be tested experimentally to validate the numerical analysis and to assess the actual performance of the PTOTHX. An advanced HX performance testing facility is available at the Center for Advanced Energy Studies (CAES) innovation laboratory. The facility is equipped with advanced pressure, flow rate, and temperature measurements using fiber optics technology for high-quality data. The fiber optics system can also extend the measurement to collect thermal stress data due to the thermal expansion of the tested prototype (if needed). An extensive test matrix initially driven by the numerical results (Task#1) will be revised for the best experimental procedure and to maximize the number of experiments within the available time. All experiments consider using water and testing near atmospheric pressure as diverse applications require. Additional fluids and other testing conditions will be considered in future project phases.

Outcomes:

(1) A set of validation data and potentially develop hydrodynamic models of the new HX design. These models would be helpful in other related numerical analyses, such as stress analysis and corrosion studies.

(2) Data will support patent application and commercialization communications.

(3) Prepare for large-scale/prototypical condition testing.

4. PROJECT MANAGEMENT & TIMELINE

The major project activities listed above are significant: design optimization is crucial to minimize the research budget (fewer prototypes to fabricate), provide a wide range of investigated parameters numerically, and collect a wide range of numerical data (develop efficient experimental testing matrix), and provide validation data experimentally. The activity outcomes are essential for supporting patent applications and seeking external funding. The validated numerical analysis with the experimental data would enable us to quantify the scaling distortion to build a more extensive scale unit of technology and predict its performance (TRL4).

All proof-of-concept outcomes would establish a high confidence level in approaching industries of interest, exciting us about the prospects of developing partnerships to perform advanced testing in large-scale laboratories and relevant environments (TRL 5-6). A strong commercialization plan support with all possible validation data would enable to move to demonstrate the technology capability in an operational environment (TRL-7), perform final evaluation and quality assurances (TRL-8) to provide vendors and businesses with qualified and efficiently demonstrated environmentally operating technology (TRL-9).

The project milestones and their corresponding timeline are summarized below:

Task / Milestone	**07/01/2025**						**06/30/2026**					
	July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**
1. Numerical Optimization (TRL1)												
2. Prototype Fabrication (TRL2)												
3. Experimental Validation (TRL3)												

The data management plan for this project outlines a comprehensive approach to handling experimental data throughout the project lifecycle. Data will be collected using standardized protocols to ensure consistency and accuracy and to document collection methods, instruments, and conditions detailed in experimental procedure documents. All data will be securely stored in a centralized database with automated backups. Quality assurance measures will include data analysis to promptly identify and correct errors and plan for extending the experimental and numerical analysis.

The Office of Research and the Contract and Grant Office at ISU double-monitor financial activities to ensure that all transactions are conducted with complete transparency and accuracy according to the state and university contract guidelines and constraints.

5. POTENTIAL ECONOMIC IMPACTS

New technology is considered one of the cutting-edge solutions that improve energy efficiency and thermal management; this technology will enhance the performance of industrial systems and potentially reduce energy costs for residential, commercial, and industrial sectors. The demand for advanced HX systems is anticipated to increase across various industries, including power generation, data centers, agriculture, and chemical processing. Idaho-based manufacturers and service providers will benefit from increased sales and exports, contributing to the state's GDP growth. The impact on Idaho's economy will be profound, driving innovation and attracting investment in the state, generating high-paying jobs, particularly in engineering, manufacturing, and research. This initiative will encourage further innovation and collaboration between local startups, universities, and large corporations, fostering a thriving clean-tech ecosystem. Additionally, the positive environmental impact will position Idaho as a leader in green technology, aligning with global sustainability trends and enhancing the state's attractiveness to investors. The expected commercial success and growing demand for advanced heat exchangers will ensure the project's profitability and establish Idaho as a key player in the global clean energy market, driving long-term economic benefits for the state and instilling confidence in the project's sustainability.

Regarding commercial viability, this HX technology's profitability relies on successful proof of concept and fluidity of validated data. The project will require significant research, development, and prototyping investments, funded through private and state incentives. The high-quality outcomes from the proof-of-concept stage are the foundation of a major potential funding source to continue technology development. Partnerships with local universities, research institutions, and industry players will be crucial in the next phase for refining the technology and ensuring its competitive advantage in the marketplace. This local collaboration will help achieve project success and make all stakeholders feel included in the journey toward commercialization.

A simple table summarizes the typical timeline for developing the new technology, moving from the proof-of-concept stage to profitability. These estimates can vary depending on factors like the complexity of the technology, funding availability, and market conditions.

	Stage	Description	Estimated Time	Key Milestones
Proof of Concept	**Concept Optimization**	Initial design and testing of the technology to validate feasibility.	1 year	Demonstration of functionality in a lab or controlled environment.
	Prototype Development	Building and testing prototypes to refine the design and improve performance.		Developing prototype(s) and optimizing materials, processes, or efficiencies.
Initial Startup	**Pilot Testing**	Deploying in a real-world, small-scale setting to test practical applications.	1 - 2 years	Successful testing in operational environments, data collection, and feedback for further refinements.
	Regulatory Approvals	Meeting safety, environmental, and industry-specific regulatory requirements.	1 year (if required)	Approval from relevant authorities, such as ASME or EPA standards compliance.
Commercialization	**Business Plans**	Scaling up for full production and entering the market.	2 - 3 years	Establishing manufacturing, marketing, and distribution channels. Initial customer adoption.
	Profitability	Achieving revenue that exceeds development and operational costs.	1 - 2 years (overlapping)	Consistent sales, positive cash flow, and a growing market share.

6. PROJECT EVALUATION

Here are some measurable criteria for assessing the success of the HX technology project:

A. *Numerical Modeling Accuracy:*

Within the first three months, achieve a deviation of less than 20 % of the designated numerical design and optimization task regarding heat transfer efficiency, pressure drop, and temperature and complete the task by the end of the fifth month (within less than 5% margin).

B. *Prototype Fabrication:*

Initiate communication with the different prototype manufacturing vendors to ensure the prototype fabrication is near or fully completed by the end of month 6 of the project.

C. ***Experimental Validation:***

Complete all experimental facility modifications during the prototype fabrication, including developing the testing matrix. Conduct facility shakedown testing during month 7 of the project in preparation to initial the actual testing (at least 2-3 experiments daily) under different operating conditions, demonstrating repeatability and reliability.

D. ***Scientific Publications:***

Submit at least one peer-reviewed journal article or conference paper based on numerical and experimental findings within the project period.

E. ***Activities and Cost Estimation:***

Develop a preliminary cost/expense analysis to ensure financial consistency with the project budget. The budget review will be conducted periodically (e.g., every 2 months) with the office of research and contract and budgeting office at Idaho State University (ISU).

These criteria ensure the project remains on track and its impact can be quantitatively assessed.

7. CHALLENGES & APPROACHES

The project activities may experience a few challenges, mainly not within the proof of concept. These challenges include funding, collaboration, and market dynamics. Sufficient funding can expedite many stages, while limited funding may cause delays. Partnerships with established manufacturers or research institutions can reduce time to market. Market dynamics determine profitability, which can vary based on competition, market demand, and adoption rates in target industries.

The data generated numerically and validated experimentally during the proof-of-concept phase would be a strong key to overcoming the challenges in the project's subsequent phases. The outcomes, including scientific publications anticipated during the proof-of-concept phase, serve as the foundation for seeking external funding. Having Idaho National Lab as a collaborator would enable us to reach out to many industries and research institutions to expand the collaboration during the project's initial startup and commercialization phases. Marketing is unpredictable, but the heat exchange technology market is increasing globally and nationally due to the diverse range of applications over the last few years and is expected to continue.

The state of Idaho is growing in population and becoming very attractive for new startup companies and business transfers from neighboring states during the last few years. The PTOTHX aligns with the needs of many Idaho resident research and consulting institutions (INL, BWXT, ISL, BGS, Walsh Engineering, and more), increases the opportunities for collaboration, increases external funding, and the establishment of new successful businesses to serve many upcoming energy-related projects (e.g., Net Zero, Microreactors, Dairy and food industries, and more) within the state of Idaho, and is key for establishing a successful marketing plan and speeding up profitability.

8. BUDGET & JUSTIFICATION

The project requests $125,000 over one year, starting 07/01/2025 through 06/30/2026, as indicated in the preproposal. The budget breakdown is provided in Appendix D: IGEM-HERC Full Proposal Budget Form (Excel sheet) and summarized herewith budget justifications:

LINE-ITEM REQUEST	JUSTIFICATION (see details below)	TOTAL REQUEST
Personnel (salary and fringe)	- Senior faculty summer salary - Two students' salary - Faculty and students' fringe benefits	$63,195
Equipment	- Three prototypes (quote attached)	$40,000
Travel	- Attending ANS or equivalent conference for faculty and one graduate student	$6,000
Other Direct Costs	- All necessary tools and parts to modify the existing experimental facility to accommodate the new prototypes. - Publication cost	$14,805 $1,000
	Total (all numbers are rounded to the nearest $100)	$125,000

A. SENIOR PERSONNEL ($40,837)

The PI is requesting a 3-month summer salary with an estimated annual increase of 3%.

B. OTHER PERSONNEL (Salary of two students = $10,000 + $6,000 = $16,000)

Graduate Ph.D. student salary of $10,000
Graduate Master or Undergraduate student(s) salary of $6,000

C. FRINGE BENEFITS ($6,358)

PI's summer salary fringe is calculated at 15.1 % of the requested salary for the summer. Student fringe benefits are charged at 1.2 % per year.

D. CAPITAL EQUIPMENT ($40,000)

Three units will be fabricated for the project's validation experiments activities. Each prototype costs $13,300 (see the attached quote), including materials (316L SS), water cutting, machining, welding, and pressure testing.

E. TRAVEL ($6,000)

The budget will be used to travel and present the research outcomes at the American Nuclear Society (ANS) 2026 Annual Meeting (Denver, Co., 05/31/2026-06/03/2026) or other related conferences (PI and one graduate student). The travel budget includes support for round-trip flight tickets, accommodation, ground transportation, and daily per diem (estimated $2.5 to $3k per person).

F. OTHER DIRECT COSTS ($15,805)

- **Materials and supplies ($14,805):**

  Research lab materials and supplies to support the project. Non-capital equipment includes critical components for experimental construction/modification and shell and instrumentation of the HX units (e.g., Piping/tubing, and associated fittings, Strut/fittings/bolts (to accommodate changes to loop support, Thermocouple wires, and pressure gauges for data collection from the test section, PC for conducting computational tasks).

- **Publication cost ($1,000):**

  Publication costs can vary depending on the journal, publisher, and publication type. For example, the ANS conference charges $100 per page, requiring them to pay the conference registration fees, which could go up to $600-$1000 depending on whether they are members.

9. EXTERNAL PARTNERS

The external (industrial) partner selected for this collaborative research is Idaho National Laboratory (INL), which has no financial commitment. INL is the US's leading national laboratory for clean energy and one of the major global players in nuclear energy development. The collaboration with INL will provide excellent access to the High-Performance Computer (HPC) system with all the necessary software required to achieve numerical optimization (Task 1). More importantly, INL provides many potential collaborations with other universities and national laboratories that could support the startup phase of technology development. Also, INL is a major partner with many nuclear and non-nuclear industries with hydrogen production and integration with renewable energy resources to achieve Net-Zero by 2030, Terra Power, Holtec International, Westinghouse, and Aalo atomic (Located in Idaho Falls). These companies are directedly supported by the Department of Energy (DOE) to demonstrate Gen IV nuclear reactor construction, which would open a great opportunity for partnership for effective commercialization and speed up probability if the new HX technology is adopted.

Please refer to Appendix B and Appendix C for senior personnel qualification and project contribution.

10. REFERENCES

[1] Fortune Business Inside Report, https://www.fortunebusinessinsights.com/industry-reports/heat-exchangers-market-100919

[2] Allied market research report, https://www.alliedmarketresearch.com/heat exchangers

[3] Ali, A., Wallace, B., Blandford, E.D., "Triple flow heat transfer with an intermediate oval-twisted tube for FHRs," NURETH18, Portland, Oregon, USA (2019).

[4] A. Ali, P. Sabharwall, "In-Plane Oval-Twisted Spiral Tube Heat Exchanger for Nuclear Applications," American Nuclear Society (ANS), Annual Meeting (2021).

[5] S. Wahlquist, A. Ali, P. Sabharwall, S. Yoon, "Novel Heat Exchanger Configuration for Enhanced Heat Transfer for Nuclear Applications," Trans. Amer. Nuclear Society, 123, 1717-1720 (2020).

[6] S. Wahlquist, A. Ali, S. Yoon, P. Sabharwall, "Laminar Flow Heat Transfer in Helical Oval-Twisted Tube for Heat Exchanger Applications," Front. Heat Mass Transf. (FHMT), 18, 35 (2022).

[7] Kyle Schroeder, Scott Wahlquist, Amir Ali, Ahmed Hamed, Piyush Sabharwall, "Numerical Analysis of Novel Plate Type Heat Exchanger with Oval-Twisted Channels," Transactions of the American Nuclear Society, 129, 1134-1137 (2023).

A&R Corporation

QUOTATION

TO:

Idaho State University
Accounts Payable Dept
921 S 8th Ave Stop 8219
Pocatello, ID 83209-8219
(208)715-4145

ATTN: SCOTT WAHLQUIST

SHIP TO:

ATTN:

Quote No.	Date	Cust No	S/M	Your Referenced Inquiry	Delivery Promise	F.O.B.	Expiration
0020522	12/20/2024	ISU	KG				30 DAYS

Item	Quantity	UM	Part	Description	Price $	Extension $
001	1.00	EA	LABOR	HEAT EXCHANGER - PTOTHX WATER JET, MACHINE, TIG WELD, ASSEMBLE AND PRESSURE TEST HEAT EXCHANGER. MATERIAL: 316L STAINLESS STEEL.	13,207.4900	13,207.49
				Total for Quote $		**13,207.49**

A&R Corporation
515 West 19 Street
Idaho Falls, ID 83402
208-529-9190

By:______________________________

APPENDIX A - FACILITIES & EQUIPMENT

Advanced Compact Heat Exchanger Technology for Efficient Energy Utilization

Principal Investigator: Amir Ali[1,2]

[1]Nuclear Engineering, Idaho State University
[2]Center of Advanced Energy Studies (CAES)
Office: (208) 533-8108; Cell: (505) 903-4767; aliamir@isu.edu

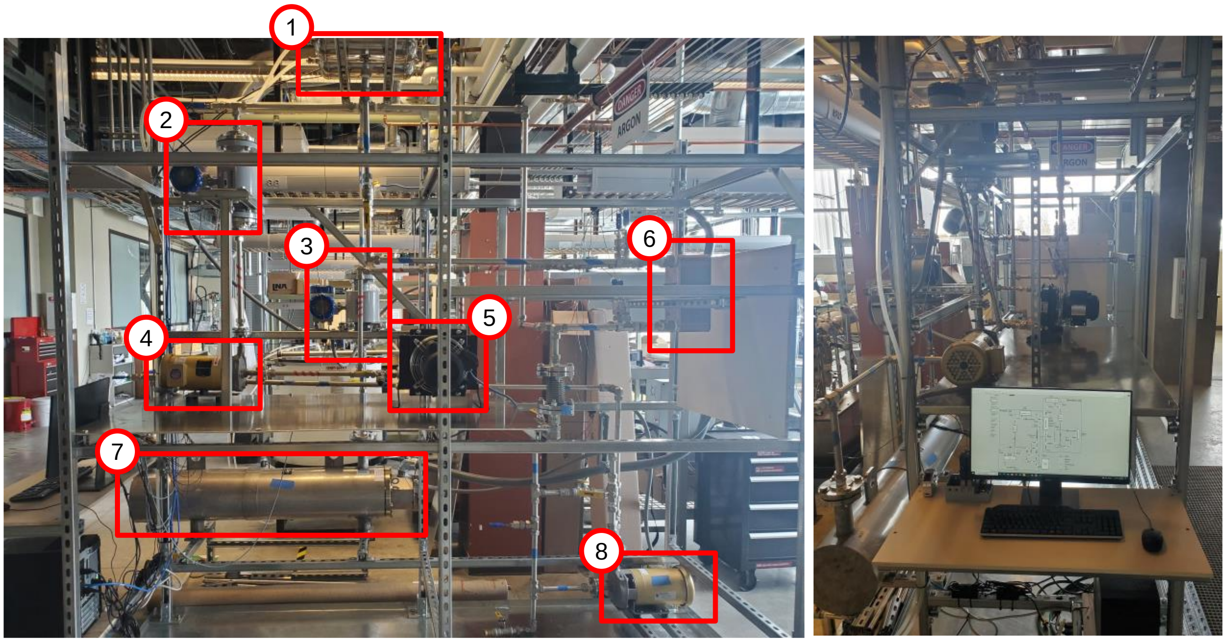
All computational tasks are conducted at the Center of Advanced Energy Studies (CAES) during the project's entire duration. CAES is a research and education consortium between the Idaho National Laboratory (INL), multiple Idahoan universities, and Wyoming University. CAES combines these five research institutions' efforts to provide timely research support on both technical and policy issues through its collaborative structure. Through collaboration with INL, the project will take advantage of all INL state-of-the-art High-Performance Computational (HPC) capabilities described below. All experimental efforts were conducted using two heat transfer facilities (HTFs) in CAES/ISU. The facility has been developed by and utilized to conduct experimental activities for advanced heat exchanger research supported by the NRC award, which started in 2022. Utilizing the operational facility would expedite the experimental efforts and possibly reduce the time to add more validation experiments. In addition, the innovation lab in CAES managed by the project PI has many other instruments that may indirectly support some project activities, including a high-temperature Goniometer and Dektak surface profilometer (see details below).

Computational Capabilities:

The INL High-Performance Computing (HPC) Center has various scientific computing capabilities to support INL's advanced modeling and simulation efforts. Falcon, the current supercomputer operated at INL, is a 34,992-core SGI ICE X distributed memory cluster with 121.5 TB total memory distributed over 972 compute nodes. Each node consists of 2 Intel Xeon E5-2695 v4 CPUs, with a performance of 36x2.10 GHz and 128 GB memory per node. Internode communications are based on FDR InfiniBand Network (56 Gbit/s), Single-Plane Enhanced Hypercube Topology. The system is operated using SUSE Linux Enterprise Server 12 Service Pack 4. The performance of this system has been measured at 1087.58 TFlops using the LINPACK benchmark. A new supercomputer named Sawtooth is also up and running. Sawtooth is a 99,792-core HPE SGI 8600 cluster with 394.875 TB total memory, distributed over 2079 computer nodes. Most (2052) nodes have 2 Intel Xeon 8268 CPUs, 48x2.90 GHz, and 192 GB memory performance. The remaining 27 nodes comprise 2 Intel Xeon 8268 CPUs, 48x2.90 GHz, and 384 GB memory. All thermal-hydraulics and structural analysis computational capabilities required to conduct and complete the tasks proposed for this project efficiently are up to date on the INL-HPC, including, for example, STARCCM+, ABAQUS, and COMSOL Multiphysics.

ISU-Heat Transfer Facility (HTF)

Experimental efforts will utilize the existing heat transfer facility (HTF) at ISU/CAES. The HTF comprises two main loops: the primary, secondary, and chilled water circuits. The heat transfer loop assigned for the water testing is designed to deliver up to 40 kW of power and can set up to 15 GPM of water at a maximum temperature of 120 ^{o}C (a single phase will be kept during the water experiments). The axial temperature is captured using a high-definition temperature fiberoptic sensor of 2 meters (~ 1000 gage/m) that can operate up to 550 ^{o}C. All control units and instrumentation are connected to the Data Acquisition System (DAQ) for signal processing and recording. An inert gas system (e.g., Argon) will create submerged jet (s). The gas loop consists of a cylindrical mixing chamber connected to the gas source to maintain a stable mass flow rate and constant inlet pressure during the experiments. The desired jet conditions will be determined according to the scaling study and WEC recommendation. A LabVIEW interface is developed to communicate with all the experimental components and record measurements.



The Heat Transfer Test Facility (HTF) in ISU/CAS Innovation Laboratory

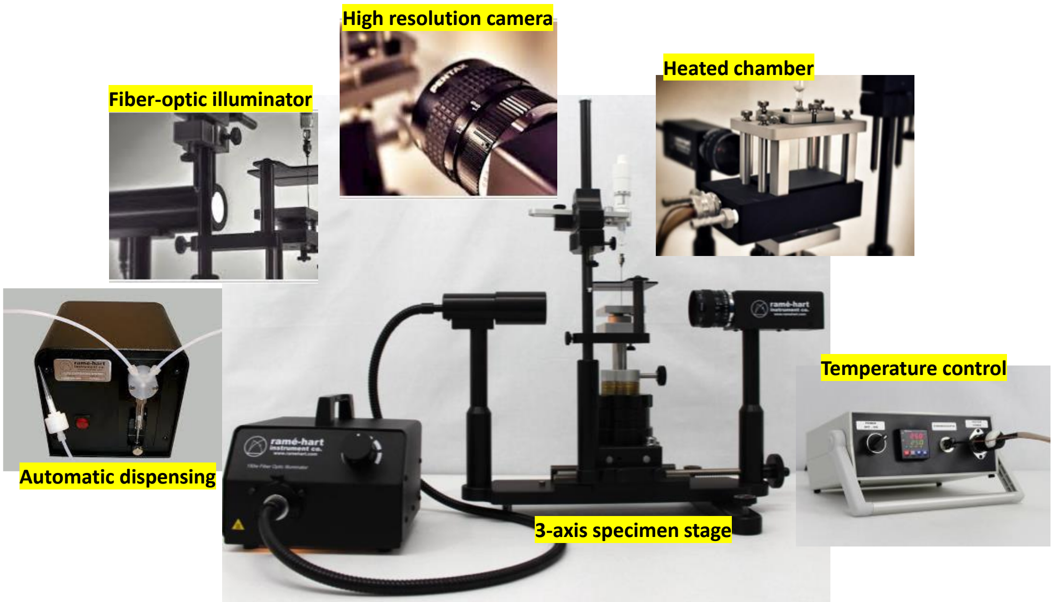
1) Expansion Tank, 2) Secondary loop flow meter, 3) Primary loop flow meter, 4) Secondary loop pump, 5) Secondary loop heat exchanger, 6) Test section, 7) 30 kW heater, 8) Primary loop pump.

Fiber Optics System

The Luna ODiSI 6000 Series provides thousands of strains or temperature and strain (vibration sensor can be added) measurements per meter of a single high-definition fiber sensor. The ultra-high-resolution data can comprehensively map the strain contour for a structure under test or the continuous temperature profile of a process in real time. The ODiSI provides actual measurement data with software-selectable gage pitch settings as dense as 0.65 mm for a 2-meter-long sensor. The maximum measurement rate for the ODiSI is 250 Hz. The ODiSI can also measure microstrain and a broad temperature range from Cryogenic to 500+ degrees C.

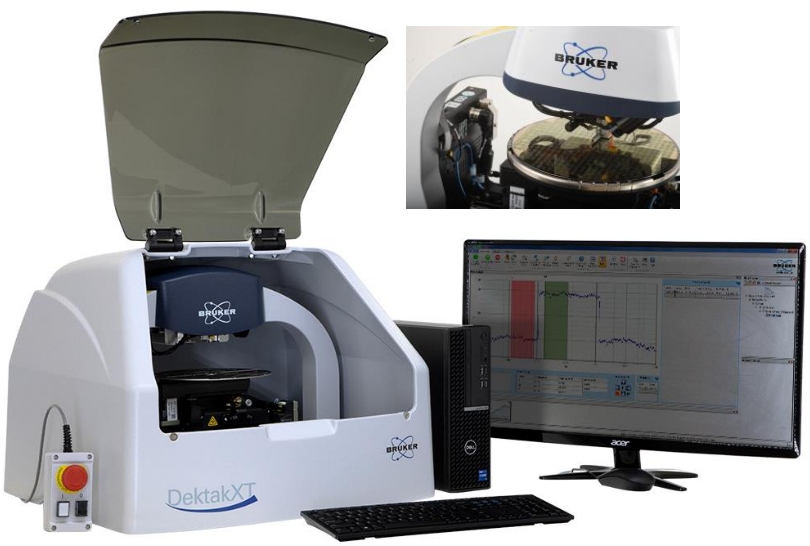
Surface Goniometer

The goniometer measures contact angle, surface tension, and surface energy. The facility has an automated dispensing system to control the droplet volume and ensure measurement repeatability. The controlled tilting base can change the specimen tilting angle to measure the advance and receding contact angles. The machine has a temperature-controlled chamber for up to 300°C under atmospheric pressure measurements. All measurements are collected and analyzed using advanced DROPimage analytical software.



Surface Profilometer

The surface profilometer (Dektak XT) is a stylus type with 1 mg force to measure surface peaks and valleys. Each scan's average roughness, Ra, is calculated from the surface topology measurements using the Dektak software. The machine can measure samples up to 5 inches in diameter. The system has a 1-millimeter standard vertical range with up to 120,000 data points per scan. The machine can measure surface flatness, waviness, and radius of curvature, as well as characterizing thin-film stress on wafers.



APPENDIX B – BIOGRAPHICAL SKETCH

Amir Ali, Ph.D.
Associate Professor and Laboratory Lead

Nuclear Engineering, Idaho State University
1784 Science Center Dr #218, Idaho Falls, ID 83402
Center of Advanced Energy Studies (CAES)
995 M Simpson Blvd, Idaho Falls, ID 83401
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OVERVIEW

Dr. Ali is an Assistant Professor who joined the Nuclear Engineering Dept. at Idaho State University in the Fall of 2019, is a resident of the Center of Advanced Energy Studies (CAES) building located inside the INL boundaries and was recently assigned a leader of the thermal-hydraulic lab in CAES. His research focuses on experimental and computational analysis of advanced reactors' thermal-hydraulic challenges to develop heat exchanger technology. Dr. Ali received his Ph.D. in (2013) and served at the University of New Mexico (UNM) as a Research Assistant Professor between 2014 and 2019. He was a thermal-hydraulic and reactor safety lab team member, leading research (PI and Co-PI) on multiple NEUP and IRP projects funded by DOE. His research focuses on developing new heat exchanger technology for molten salt and liquid metal-cooled reactors (Co-PI, NEUP, and PI- KIROS POWER). He constructed a molten salt loop to investigate the accelerated corrosion of bimetallic alloys in FLiBe as a molten salt structure alloy candidate (NEUP, Co-PI). He received the NEUP infrastructure reactor upgrade award for replacing the control rod drive mechanism of the ISU AGN-201M reactor with a modern design. Dr. Ali has gained experience in boiling heat transfer on micro-structured surfaces for immersion cooling applications and heat pipe technology for microreactors. Dr. Ali has acquired a long practice as a Mechanical engineering consultant for energy building systems, including fire protection, HVAC, and plumbing systems.

EXPERIENCE

Aug. 2023 - current	Associate Professor, Nuclear Engineering, Idaho State University (ISU)
Aug. 2019 - 2023	Assistant Professor, Nuclear Engineering, Idaho State University (ISU)
Jan. 2020 - Current	Innovation Lab. Lead, Center of Advanced Energy Studies (CAES)
2015 - Current	Research professor and Adjunct Lecturer, Nuclear Engineering Depts., University of New Mexico (UNM)
2014 - 2015	Postdoctoral fellow, Nuclear Eng., University of New Mexico (UNM)
2007 - 2014	Research assistant, Nuclear Eng., University of New Mexico (UNM)

EDUCATION

2014 Ph.D., w/distinction, Mechanical Engineering; University of New Mexico, USA
2004 M.Sc. Mechanical Engineering; University of Benha, Egypt
1996 BS w/Honors, Mechanical Engineering; University of Benha, Egypt

SELECTED RECENT PUBLICATIONS Google Scholar (733), h (11), I10 (13)

[1] **Amir Ali**, Piyush Sabharwall," In-Plane Oval-Twisted Spiral Tube Heat Exchanger for Nuclear Application," Submitted to ANS Annual Meeting, Jun. 2021.

[2] Scott Wahlquist, **Amir Ali**," Heat Transfer in a Randomly Packed Spheres for FHR Reactors," Submitted to ANS Annual Meeting, Jun. 2021.

[3] Scott Wahlquist, Su-Jong Yoon, Piyush Sabharwall**, Amir Ali**, 2020" Novel Heat Exchanger Configuration for Enhanced Heat Transfer in Nuclear Applications," ANS winter meeting, Nov.2020.

[4] **Amir Ali**, Hyun-Gil Kim, Khalid Hattar, Samuel Briggs, Dong Jun Park, Jung Hwan Park, Youho Lee, 2020 "Ion irradiation effects on Cr-coated zircaloy-4 surface wettability and pool boiling critical heat flux," Nuclear Engineering and Design, Vol. 362, 110581.

[5] **Amir Ali**, 2020 "Thermal performance and stress analysis of heat spreaders for immersion cooling applications," Applied Thermal Engineering, Vol. 181, 115984.

[6] **Amir Ali**, Lane B. Carasik, Arturo Cabral," Towards Understanding the Thermal-Hydraulic Distortion of using Surrogate Fluids for FHRs Development," ANS winter meeting, Nov.2020.

[7] **Amir Ali**, Brayan Wallace, Edward Blandford, 2019 "Triple flow heat exchanger with intermediate oval twisted tube for FHRs," 18th International Topical Meeting on Nuclear Reactor Thermal Hydraulics NURETH-18, Portland, Oregon.

[8] Maolong Liu, Joel Hughes, **Amir Ali**, and Edward Blandford, 2018 "Conceptual Design of a Freeze-tolerant Direct Reactor Auxiliary Cooling System for Fluoride-salt-cooled High-temperature Reactors," Nuclear Engineering and Design, Vol. 335, 54-70.

[9] **Amir Ali,** Jacob Gorton, Nicholas Brown, Kurt Terrani, Youho Lee, Edward Blandford, 2018 "Surface Wettability and Pool Boiling Critical Heat Flux of Accident Tolerant Fuel Cladding-FeCrAl Alloys," Accepted for publication- Nuclear Engineering and Design Journal, Vol. 338, 218-231.

[10] Bryan Wallace, **Amir Ali**, Joel Hughes, Edward Blandford, 2017 "Double wall Twisted Tube Heat Exchanger Simulation and Validation," Submitted to American Nuclear Society Winter Meeting.

PENDING PATENTS

[1] **Amir Ali**, US Patent "Double Helical - Inner Twisted Tube Heat Exchanger" (under review)

[2] Mohamed El-Genk and **Amir Ali**, US Patent "High-Efficiency Wavy Channels Printed Circuit Heat Exchanger" (under review)

SYNERGISTIC ACTIVITIES

- Reviewer of a series of Mechanical and Nuclear Engineering Journals including Journal of Applied Thermal Engineering, Journal of Nuclear Engineering and Design, Journal of Nuclear Engineering Materials, Journal of Nuclear Technology, and Annals of Nuclear Energy.
- Member: The American Society of Mechanical Eng. (ASME) and American Nuclear Society (ANS).
- Session chair/cochair, multiple ANS Meetings on Thermal Hydraulics
- Reviewer for funding programs: US DOE (NEUP & SBIR)
- Graduate Council Representative & Graduate Faculty

Ahmed Hamed, Ph.D.

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Objectives and Research Interests

I am a computational scientist motivated to develop high-fidelity computational models using hybrid data-driven and physics-based approaches that will contribute to the discovery of novel materials with outstanding properties in harsh environments facilitating highly efficient integration of clean energy systems toward achieving the net-zero carbon emission goals. My research interest encompasses multiscale multiphysics modeling and simulation of materials behavior in extreme environment, particle and thermal transport, microstructural evolution, materials kinetics & thermodynamics, radiation damage & effects, solid & statistical mechanics, granular flow, machine learning, data analytics, and image processing.

Employment History

2021 – present	**R&D Staff Scientist,** Idaho National Laboratory, ID, USA.
2023 – present	**Allied Graduate Faculty,** Department of Nuclear Engineering, Idaho State University. **Joint Appointee,** Department of Electrical & Computer Engineering, Idaho State University, ID, USA.
2018 – 2021	**Post-doctoral Research Associate,** School of Mechanical/Materials Engineering, Purdue University, IN, USA.
2013 – 2017	**Graduate Research Assistant,** School of Nuclear Engineering, Purdue University, IN, USA.
2009 – 2013	**Graduate Teaching Assistant,** Department of Nuclear, Plasma & Radiological Engineering, University of Illinois, Urbana–Champaign, IL, USA.
2010, 2011, 2012	**Summer Research Aide,** Nuclear Engineering Division, Argonne National Laboratory, Lemont, IL, USA.
2008 – 2009	**Research Aide,** Masdar Institute of Science and Technology, Abu Dhabi, UAE.
2006 – 2008	**Military Service,** Air Defense Academy, Alexandria, Egypt.

Education

2013 – 2017	**Ph.D., Purdue University** Nuclear Engineering, with concentration in Materials. Double Major in Computational Science & Engineering (CSE).
2009 – 2013	**Ph.D. candidate, University of Illinois** Nuclear Engineering. Degree: not completed, transferred to Purdue University.
2001 – 2006	**B.Sc. Alexandria University, Egypt** Cum Laude, Honors in Nuclear Engineering. Six graduate–level courses completed.

Selected Research Publications

Journal Articles

1. Z. Tasnim, Q. Chen, Y. Xia, **A. Hamed**, J. Klinger, R. Navar, and B. Davis, "Discrete element modeling of irregular-shaped soft pine particle flow in an ft4 powder rheometer," *Powder Technology*, vol. 450, p. 120 437, 2025, ISSN: 0032-5910. DOI: https://doi.org/10.1016/j.powtec.2024.120437.
2. Y. Xia, R. Navar, Z. Tasnim, **A. Hamed**, J. Klinger, B. Davis, and Q. Chen, "The role of flexural particles in the shear flow of pine residue biomass: An experiment-informed dem simulation study," *Powder Technology*, vol. 440, p. 119 771, 2024, ISSN: 0032-5910. DOI: https://doi.org/10.1016/j.powtec.2024.119771.

3. **A. Hamed**, Y. Xia, N. Saha, J. Klinger, D. N. Lanning, and J. H. Dooley, “Particle size and shape effect of crumbler® rotary shear-milled granular woody biomass on the performance of acrison® screw feeder: A computational and experimental investigation,” *Powder Technology*, vol. 427, p. 118 707, 2023, ISSN: 0032-5910. DOI: https://doi.org/10.1016/j.powtec.2023.118707.
4. Y. Xia, J. Liu, R. Kancharla, J. Li, S. M. Hatamlee, G. Ren, V. Semeykina, **A. Hamed**, and J. J. Kane, “Insights into the 3d permeable pore structure within novel monodisperse mesoporous silica nanoparticles by cryogenic electron tomography,” *Nanoscale Adv.*, vol. 5, pp. 2879–2886, 11 2023. DOI: 10.1039/D3NA00145H.
5. **A. Hamed**, S. Rayaprolu, G. Winther, and A. El-Azab, “Impact of the plastic deformation microstructure in metals on the kinetics of recrystallization: A phase-field study,” *Acta Materialia*, vol. 240, p. 118 332, 2022, ISSN: 1359-6454. DOI: https://doi.org/10.1016/j.actamat.2022.118332.
6. **A. Hamed**, Y. Xia, N. Saha, J. Klinger, D. N. Lanning, and J. Dooley, “Flowability of crumbler rotary shear size-reduced granular biomass: An experiment-informed modeling study on the angle of repose,” *Frontiers in Energy Research*, vol. 10, 2022, ISSN: 2296-598X. DOI: 10.3389/fenrg.2022.859248.
7. W. Jin, Y. Lu, F. Chen, **A. Hamed**, N. Saha, J. Klinger, S. Dai, Q. Chen, and Y. Xia, “On the fidelity of computational models for the flow of milled loblolly pine: A benchmark study on continuum-mechanics models and discrete-particle models,” *Frontiers in Energy Research*, vol. 10, 2022, ISSN: 2296-598X. DOI: 10.3389/fenrg.2022.855848.
8. Y. Xia, Q. Rao, **A. Hamed**, J. Kane, V. Semeykina, I. Zharov, M. Deo, and Z. Li, “Flow reduction in pore networks of packed silica nanoparticles: Insights from mesoscopic fluid models,” *Langmuir*, vol. 38, no. 26, pp. 8135–8152, 2022, PMID: 35731695. DOI: 10.1021/acs.langmuir.2c01038. eprint: https://doi.org/10.1021/acs.langmuir.2c01038.
9. W. R. Deskins, **A. Hamed**, T. Kumagai, C. A. Dennett, J. Peng, M. Khafizov, D. Hurley, and A. El-Azab, “Thermal conductivity of ThO2: Effect of point defect disorder,” *Journal of Applied Physics*, vol. 129, no. 7, p. 075 102, Feb. 2021, ISSN: 0021-8979. DOI: 10.1063/5.0038117.
10. C. A. Duarte, **A. Hamed**, J. D. Drake, C. J. Sorensen, S. F. Son, W. W. Chen, and M. Koslowski, “Void collapse in shocked -hmx single crystals: Simulations and experiments,” *Propellants, Explosives, Pyrotechnics*, vol. 45, no. 2, pp. 243–253, 2020. DOI: https://doi.org/10.1002/prep.201900251. eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/prep.201900251.
11. M. N. Sakano, **A. Hamed**, E. M. Kober, N. Grilli, B. W. Hamilton, M. M. Islam, M. Koslowski, and A. Strachan, “Unsupervised learning-based multiscale model of thermochemistry in 1,3,5-trinitro-1,3,5-triazinane (rdx),” *The Journal of Physical Chemistry A*, vol. 124, no. 44, pp. 9141–9155, 2020, PMID: 33112131. DOI: 10.1021/acs.jpca.0c07320. eprint: https://doi.org/10.1021/acs.jpca.0c07320.
12. **A. Hamed** and A. El-Azab, “Peak intrinsic thermal conductivity in non-metallic solids and new interpretation of experimental data for argon,” *Journal of Physics Communications*, vol. 2, no. 1, p. 015 022, Jan. 2018. DOI: 10.1088/2399-6528/aaa36f.

Conference Proceedings

1. A. Dev, Y. Mohamed, **A. Hamed**, Y. Xia, R. Seifert, and M. Fouda, “Automated phenotyping of herbaceous biomass using U-Net architecture for µ-CT images segmentation,” in *2024 IEEE International Conference on Artificial Intelligence, Blockchain, and Internet of Things (AIBThings), Mount Pleasant, MI, USA*, 2024.
2. K. Schroeder, S. Wahlquist, A. Ali, **A. Hamed**, and P. Sabharwall, “Numerical analysis of novel plate type heat exchanger with oval-twisted channels,” in *ANS Transactions*, vol. 129, 2023, pp. 1134–1137. DOI: https://doi.org/10.13182/T129-42634.

APPENDIX C - SENIOR PERSONNEL

Advanced Compact Heat Exchanger Technology for Efficient Energy Utilization

Principal Investigator: Amir Ali[1,2]

[1]Nuclear Engineering, Idaho State University
[2]Center of Advanced Energy Studies (CAES)
Office: (208) 533-8108; Cell: (505) 903-4767; aliamir@isu.edu

1. PROJECT SUMMARY

Plate-type HXs are compact and efficient designs that have been utilized for many decades in diverse applications. Further performance improvement and size reduction can be achieved by utilizing several small and complex geometrical channels. Currently, advanced manufacturing technologies enable the design and fabrication of compact-type units with complicated channel geometries to achieve the highest performance and meet the compact criteria of innovative HX technology. Over the last few years, the oval twisted tube geometry has shown highly improved performance in many HX design concepts, including straight oval-twisted shell and tube, oval-twisted spiral, and oval-twisted helical tube HX concepts, but not the compactness which is becoming a desirable condition in advanced HX technology.

The proposed HX design concept combines the compactness of plate-type HXs and twisted channels, which provide additional turbulence and flow swirl enhancement in addition to the compactness nature of the design (Figure 1). The new concept is expected to:

1. Enhance the fluid mixing and convection heat transport (high heat transfer efficiency).
2. Provides tube self-support when used in arrays (no tube supports or baffles).
3. Increase heat transfer per unit volume when tubes are in crossflow arrangement (increased compactness).
4. Minimize or eliminate stagnation points (low or less fouling).

The project has three major tasks to be completed within the project period. A summary of tasks, expected timeline, and outcomes are summarized in the table below (please refer to the main project proposal for details).

Task #	Description	Outcome (s)	Estimated time (Months)
1	Design Optimization	(1) The best geometrical and operational parameters for maximum performance. (2) Feed to fabricate efficient prototypes to minimize budget expenses (Task#2). (3) Supports the development of the experimental test matrix (Task#3)	4
2	Prototype Fabrication	(1) Optimized multiple units of prototype (oval-twisted and circular channels)	3

3	Experimental Validation	(1) A set of validation data and potentially develop hydrodynamic models of the new HX design. (2) Data will support patent application and commercialization communications. (3) Prepare for large-scale/prototypical condition testing.	5

2. PROJECT EXECUTION

All project tasks (Tasks 1 through 3) will be conducted at the Center of Advanced Energy Studies (CAES) during the project's entire duration under supervision by the project PI (Prof. Amir Ali). Dr. Ali has much experience designing and building single- and multiple-phase small-scale experimental facilities using water, simulant fluids, and molten salt to evaluate HX performance and structure materials. CAES is a research and education consortium between the Idaho National Laboratory (INL), multiple Idahoan universities, and Wyoming University. CAES combines these five research institutions' efforts to provide timely research support on both technical and policy issues through its collaborative structure. All experimental efforts were conducted using two heat transfer facilities (HTFs) in CAES/ISU. The facility has been developed by and utilized to conduct experimental activities for advanced heat exchange research supported by the NRC award, which started in 2022. Utilizing the operational facility would expedite the experimental efforts and possibly reduce the time to add more validation experiments. In addition, the innovation lab in CAES managed by the project PI has many other instruments that may indirectly support some project activities, including a high-temperature Goniometer and Dektak surface profilometer.

At this stage, the INL collaborator will only provide access to INL state-of-the-art High-Performance Computational (HPC) capabilities to enable the ISU team to perform the computational work. The INL collaborator (Dr. Ahmed Hamed) will be involved in the project's upcoming phases, including large-scale testing and commercialization activities.

Please refer to the detailed resume (Appendix-B) for more information about the project's senior personnel.