INL/RPT-23-74257
Revision 0

Thermal Integration of DETAIL Systems

Installation of MAGNET-TEDS HX

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ABSTRACT

A thermal connection between the Microreactor AGile Non-nuclear Experimental Testbed (MAGNET) and the thermal energy distribution system (TEDS) has been a key part of the Dynamic Energy Transport and Integration Laboratory (DETAIL) plan since the development of the Integrated Energy Systems Roadmap in 2020. This connection provides an expanding demonstration capability for integrated system operations. The thermal connection between MAGNET and TEDS required the selection of a heat exchanger and valves to isolate flow. Research staff within the NEET Crosscutting Technology Development program selected equipment after receiving proposals from multiple vendors. A helical coil heat exchanger from Graham Corporation was selected for its small volume relative to its heat transfer surface area to fit in the limited space available. Triple offset butterfly valves with pneumatic actuators from Flowserve were selected to isolate and/or control flow of the hot gas through the heat exchanger. Staff from Idaho National Laboratory's (INL) Facilities and Site Services Engineering department designed the piping and structural support. A mechanical construction firm was contracted to install the system. This report documents the design and construction of this thermal connection.

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CONTENTS

FIGURES

TABLES

ACRONYMS

CAD	Computer-aided drafting
DOE	Department of Energy
DETAIL	Dynamic Energy Transport and Integration Laboratory
HX	Heat exchanger
INL	Idaho National laboratory
MAGNET	Microreactor agile non-nuclear experimental test
NPP	Nuclear power plant
TEDS	Thermal Energy Distribution System

Thermal Integration of DETAIL Systems

INTRODUCTION

Nuclear power plants (NPPs) operate most efficiently and economically when run at a constant power output. However, the growth of renewable, and intermittent, sources, such as wind and solar, has created grid dynamics that do not always support baseload generation by NPPs. A solution to intermittent generation could help the U.S. in their decarbonization efforts by allowing NPPs to compete more easily with natural gas, wind, and solar.

A Dynamic Energy Transport and Integration Laboratory (DETAIL) is being constructed at Idaho National Laboratory (INL), which will demonstrate integrated energy systems. DETAIL will allow demonstrations of transient distribution of electricity and thermal energy for power generation, energy storage, and industrial use in a flexible setting [1].

The thermal energy distribution system (TEDS), one part of DETAIL, is a system that provides a platform for testing heat transfer components, distribution systems, instrumentation, and controls for hybrid generation of electrical power and non-electrical products [1].

Funded by the DOE Microreactor Program, the Microreactor AGile Non-nuclear Experimental Testbed (MAGNET) was developed to test prototype microreactor components in a non-nuclear environment. This capability supports technology maturation and reduces uncertainty and risk for microreactor developers [2].

A thermal connection between (MAGNET) and TEDS is a key element of the DETAIL [3]. A thermal connection between these two test beds enables true integrated energy system demonstration capability within DETAIL by providing an alternative heat source that closely emulates a novel reactor system. To integrate these two systems, a heat exchanger and valves, which isolate flow, were selected. INL’s Facilities and Site Services Engineering designed the piping and structural to support. Finally, a mechanical construction firm was contracted to install the system. This report documents the design and construction of this thermal connection.

DESIGN DETAILS

The following section describes the general requirements and operational parameters used to design the thermal connection to include piping, valves, and the heat exchanger. These requirements and parameters formed the selection basis for the components and defined the design temperature and design pressure for the ASME B31.3 piping design.

Heat Exchanger (HX)

A gas-to-oil heat exchanger (HX) that could meet system design constraints on both sides was required. Suppliers and manufacturer’s representatives were contacted to select and provide quotes for a heat exchanger meeting the requirements listed in Table 1.

Two types of HXs were proposed for this application: a traditional shell-and-tube and a helical coil. A traditional shell-and-tube HX from a Spanish heat transfer company, called XLG Heat Transfer S.L., met system operating parameters but posed a piping design challenge since it was larger than the space available in the proposed location. This proposed shell-and-tube HX was a single pass, counterflow design of 304/316L stainless steel construction. See Figure 1 for a general diagram of this HX type.

Table 1. MAGNET-to-TEDS HX design parameters.

Gas Side		Oil Side	
Fluid	Nitrogen	**Fluid**	Therminol 66
Design Pressure	22 bar	**Design Pressure**	10.3 bar (150 psig)
Nominal Operating Pressure	20 bar	**Nominal Operating Pressure**	1 bar (14.5 psig)
Design Temperature	650°C	**Maximum Film Temperature**	375°C
Nominal Inlet Temperature	600°C	**Nominal Inlet Temperature**	325°C
Nominal Outlet Temperature	Heat balance (calculated)	**Nominal Outlet Temperature**	225°C
Flow Rate	0.938 kg/s	**Flow Rate**	14 gpm

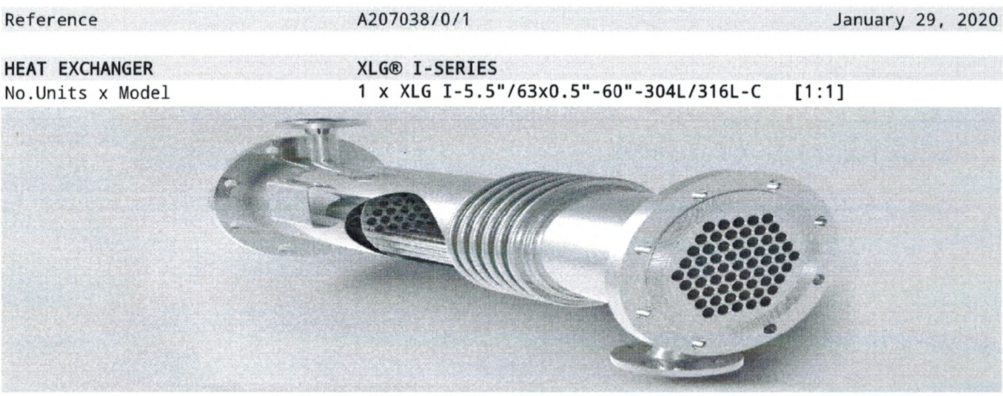

Figure 1. Single pass shell-and-tube HX

The second proposed HX was a variation on the shell-and-tube design called a helical coil HX. In this design, the tubes are coiled inside a shell allowing a greater surface area per unit volume. Figure 2 and Figure 3 show details of a helical coil HX.

Figure 2. Typical helical coil and manifolds [4]

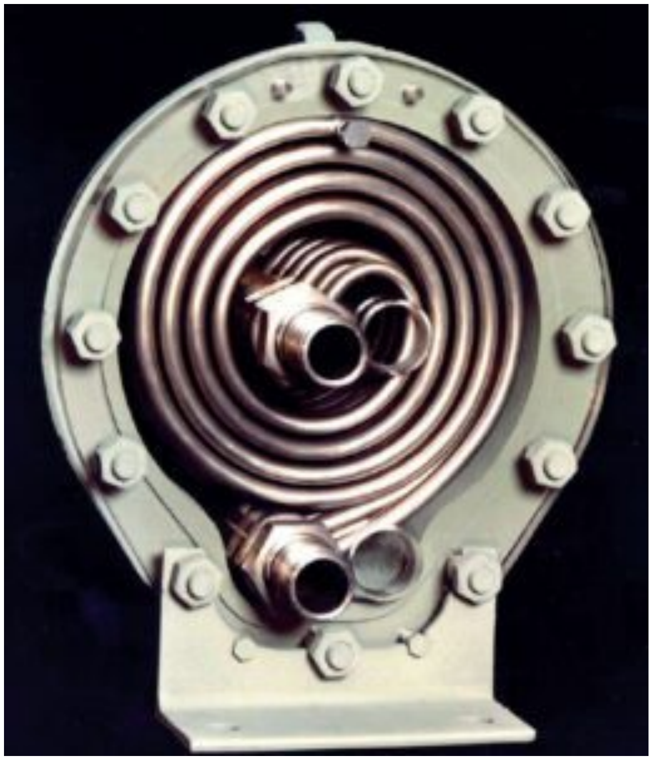

Figure 3. Sectional view of helical coil HX [4]

The traditional HX was less expensive, but limited space and the piping design made use of the single pass HX challenge. This option would have resulted in increased piping installation costs.

The helical coil HX, while a bit more expensive, saved a significant amount of effort in piping design due to limited space availability. Graham Corporation, a U.S.-based fluid, power, and heat transfer equipment manufacturing company, supplied the helical coil HX.

Valves

Remotely actuated valves were required to isolate the HX from MAGNET due to the valves' elevated location. Both pneumatic and electric actuators were quoted for this application. Pneumatic actuators use compressed air, solenoid valves, and cylinders to open and close the valves. Electric actuators use electric motors to achieve the same purpose. Pneumatic valves were chosen because TEDS already uses compressed air to actuate valves and has a compressed air installation in place and because pneumatic actuators have a shorter lead time and lower cost than electric motors.

For the gas side, 22 bar, 650°C, and 0.938 kg/s were provided as inputs to multiple valve vendors. The combination of pressure, temperature, and gas proved too high for every vendor approached except for Flowserve, a U.S.-based flow control equipment manufacturer. Flowserve provided a quote for a Durco TX3, triple offset, butterfly valve with A351 CF10M (high alloy stainless steel) body and disk and an Inconel 718 + Stellite 21 seat. These materials were chosen to stand up to the high temperature, high velocity gas flow. Figure 4 shows a general configuration for the valve chosen for the MAGNET-TEDS HX.

Figure 4. General valve configuration

Piping and Structural Design

The piping design centered around locating the HX near the MAGNET flanges, where gas would enter the HX because the 304H stainless steel piping of MAGNET is significantly more expensive than the carbon steel piping from TEDS. See Figure 5 for an isometric view of the piping layout.

The piping was designed and constructed to meet all applicable requirements of ASME B31.3-2018, “Process Piping.” The Therminol 66 piping has a design pressure of 6.9 bar (100 psi) and a design temperature of 340°C (644°F). The gas piping has a design pressure of 22 bar (320 psi) and a design temperature of 650°C (1202°F). Both align with design parameters for their respective systems (TEDS and MAGNET).

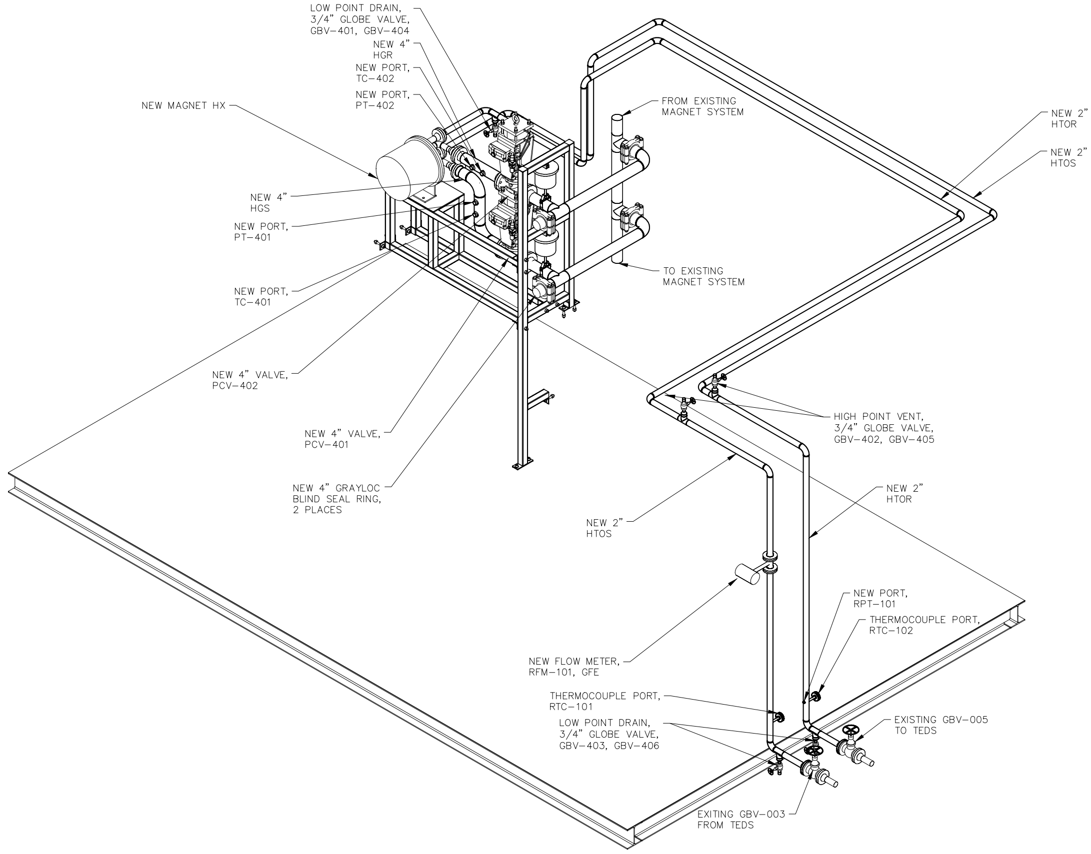

Figure 5. Isometric view of MAGNET-to-TEDS layout

PROCUREMENT AND CONSTRUCTION

Procurement for the MAGNET-to-TEDS HX components began in December 2021. The HX was originally quoted in 2020. By 2021, supply chain issues related to the COVID pandemic made high-carbon stainless steel alloys, which were required for the temperatures and pressures on the gas side, very difficult to obtain. The HX manufacturer could not obtain raw materials to stand by their original quote and could only quote a HX made of Inconel, which would result in higher cost. To switch to a different HX configuration would have required a significant amount of piping design rework.

A comparison was made of the additional costs associated with switching to Inconel construction for the HX versus piping design rework. This comparison led to the decision to switch to Inconel, but the manufacturer continued to have challenges in procuring raw materials. The purchase request was submitted to INL procurement early in December of 2021, but INL did not receive the HX, until January of 2023.

The valves were originally forecast to be the critical path procurement item as they had an eight-month lead time. The purchase request was submitted at the same time as the HX. INL received the valves in early August of 2022. The pipe installation was scheduled around the arrival of the valves with provisions to complete work to a point where the HX could be set in place upon receipt.

During construction, it was discovered that sections of the MAGNET installation differed from the construction drawings. One section of piping was anchored to a fixed point, whereas the drawings reflected that this section was not designed to be supported. Since the HX nozzles were not designed with a margin for additional loading from thermal expansion of the attached piping, this discrepancy required some last-minute piping geometry changes and procurement of thermal expansion joints. Figure 6 shows these joints.

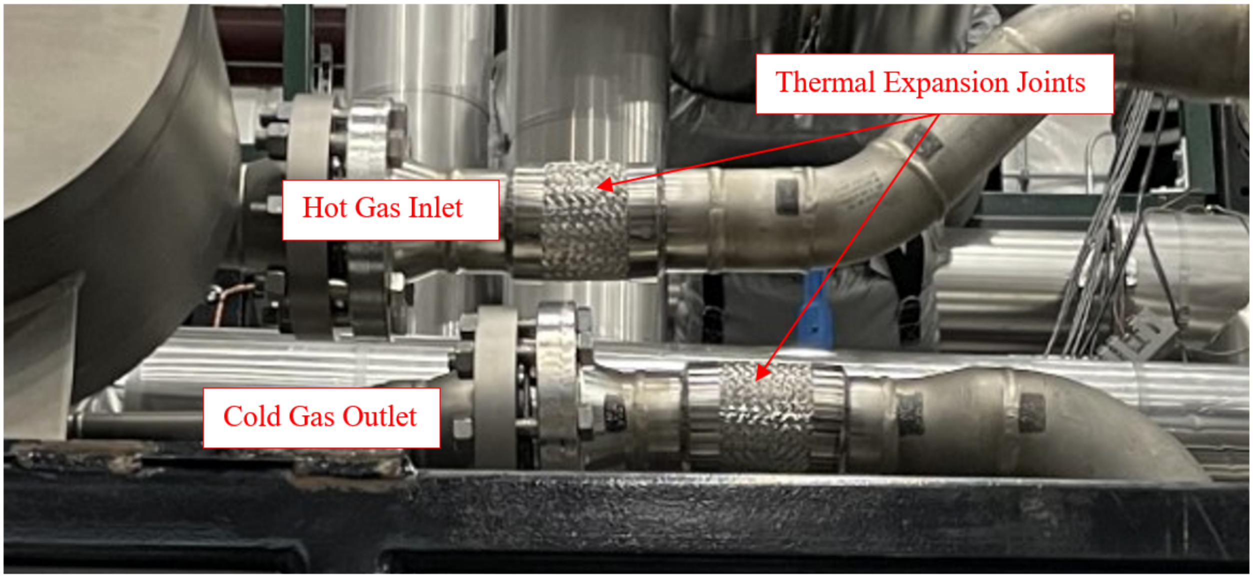

Figure 6. Thermal expansion joints.

CONCLUSION

Piping installation was completed on August 10, 2023. The piping was insulated and will be ready for operational testing when a test article is available for MAGNET. Overall, the project suffered substantial delays relative to the initial schedule. Some delays resulted from supply chain issues such as low supplies of high-carbon stainless steel alloy. Additionally, communication between the HX supplier and INL were not as open as they should have been; the supplier did not always openly communicate material delivery delays with INL and INL was not always prompt in replying with drawing approvals or comments. The conflict between new construction and as-built conditions for MAGNET could have been prevented with increased program funding to support the update of the original three-dimensional computer-aided drafting (CAD) model with details of the as-built piping configuration.

Figure 7 shows the final installation of the MAGNET-TEDS HX and associated piping and valves.

Figure 7. MAGNET-TEDS HX installation photo.

REFERENCES

1. Stoots, C. A., et al. 2018. "Thermal Energy Delivery System Design Basis Report. " INL/EXT-18-51351, Idaho National Laboratory, Idaho Falls, Idaho. https://doi.org/10.2172/1756571.

2. Morton, T.J. 2023. "Development, Construction, and Operation of a Non-Nuclear Microreactor Experimental Capability." Master's Thesis, University of Idaho, 2023. ProQuest (30572516). https://www.proquest.com/docview/2859530114.

3. Bragg-Sitton, S. M., et al. 2020. "Integrated Energy Systems: 2020 Roadmap." INL EXT-20-57708, Idaho National Laboratory, Idaho Falls, Idaho. https://doi.org/10.2172/1670434.

4. Heat Exchanger World. 2022. "Compact Technology: Graham Heliflow Heat Exchanger. " Accessed August 2, 2023. https://heat-exchanger-world.com/compact-technology-graham-heliflow-heat-exchanger/.