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An Introduction to the
HeatSponge Rainmaker Condensing Hydronic Economizer

Ever increasing pressures for improved efficiency has driven the evolution of boiler equipment technology and hydronic heating system engineering. The laws of thermodynamics apply equally to all equipment and show no preference to any one approach over another. Evolutionary leaps in performance have been driven by technological innovation that had the ability to shift the course of entire markets. In much the same way the advent of the condensing boiler represented a major evolution of technology 20 years ago so too does the development of condensing hydronic economizers today.

Latent energy is the largest component of total efficiency losses in modern boilers. Water formed in the chemical process of combustion immediately absorbs energy in the furnace turning it into a vapor. The latent heat of vaporization consumes around 1,000 btu's per pound of vapor formed. These latent losses represent well over 10% of the total input of natural gas to a boiler and over half of all losses.

For decades high pressure steam boilers were the standard source of energy for hydronic heating systems. While some high-pressure steam was needed for humidification, laundry, and commissary uses, the majority of the steam generated inside of the boiler was sent to an instantaneous heat exchanger to heat a circulating comfort heating hot water loop. High pressure steam boilers are rugged, long lived, and have the ability to fire standard fuel oil when gas is unavailable, however they are limited to a maximum fuel-to-steam efficiency of around 82%. The reason for this is the temperature of the steam water mixture inside of the boiler. A boiler is a heat exchanger. Fuel burned in the furnace transfers its energy largely in the form of radiant energy with the furnace accounting for around 40% of all heat exchanged. The products of combustion leave the furnace at temperatures around 1,800 degrees F and travel into the generating bank of a water tube boiler or the firetubes on a scotch-marine boiler where a change to a convective heat transfer occurs. Most high-pressure industrial steam boilers operate under 150 psig which has a corresponding saturation temperature of 366 degrees F. This temperature is a "hard-limit" limiting the amount of energy the exhaust gases can transfer into the boiler. Most industrial steam boilers have an approach at their best of 50 degrees F over saturation meaning a boiler generating saturated steam at 150 psig is most likely only going to be able to exchange energy to around 400 degrees F before the requirement for additional heating surface becomes impractical. Steam boiler economizers are used to extract some of the energy in the exhaust expelled from the boiler transferring it into boiler feedwater, typically at temperatures between 180- and 227-degrees F, to improve the efficiency by approximately 2% to 3%. Exhaust gases that go to atmosphere around 300 degrees F represent a complete loss of the latent energy and sizeable sensible losses as well totaling on average 18% of input.

Conventional hot water boilers bypass the generation of steam and need for an external heat exchanger by actually flowing the circulating comfort heat water directly though the boiler. Common circulating temperatures were no lower than 140 degrees F return water to the boiler supplying at 160 degrees F, the temperature differential commonly 20 degrees F as to limit differential expansion stresses on the boiler. The reduced temperature of the water inside of the boiler presents an ability for additional sensible heat transfer and its corresponding increase in overall efficiency beyond what is possible in a higher temperature steam boiler. Exiting exhaust gas temperatures however must be maintained above the dew point of the exhaust gas, approximately 135 degrees F on a natural gas fired boiler at 15% excess air. This is the temperature at which the vapor formed during combustion will begin to convert back to a liquid which must be avoided in a conventional boiler as the slightly acidic condensate would quickly corrode a boiler not manufactured of corrosion resistant materials. Hot water boiler heating systems must also bear the additional expense of needing to install smaller high pressure steam boilers to provide the steam required for use in the facilities. This leaves end users with purchasing, installing, and operating multiple boiler types in the same boiler plant at additional cost and complexity.

The development of the condensing boiler introduced corrosion-resistant materials of construction to hot water boilers allowing them to operate at water temperatures that enabled the condensing of the water vapor. Condensing boilers are able to achieve efficiencies well into the mid ninety-percent range. Condensing boilers allow for maximum practical boiler efficiencies which are now limited by the lowest operating water temperatures that still provide a suitable level of heating to the building. While representing the high point of the chase for ever-increasing efficiencies, condensing boilers have short-comings of their own. Most notable is that these boilers are extremely expensive. While the latent recovery only represents around 10% of the total heat transfer, because the entire boiler is subject to condensing temperatures the entire pressure vessel must therefore be manufactured of corrosion resistant materials such as stainless steel or corrosion resistant aluminum. These boilers also tend to be limited in their maximum size as a consequence of the reality of their unique construction. Perhaps one of the largest detriments is an inability for all but the most expensive and temperature types of condensing boilers to accommodate dual-fuel firing. Most condensing boilers are limited to gas-only firing and even those boilers that have the ability to fire a standby #2 fuel oil require the operating temperatures to be significantly increased to avoid the significantly acid formation associated with oil firing compared to gas.

The formation of vapor in the combustion process is not the only place where latent energy comes into play on the design of a heating system. Turning water into steam requires a phase change, like the formation of vapor in the furnace of a boiler this latent heat of vaporization requires approximately 1,000 btu's for every pound of water changed into steam. This means every pound of steam will deliver 1,000 btu's when condensed. Hot water boilers however only utilize a sensible heat exchange which for water represents 1 btu per pound per degree F. A hot water boiler with a 20-degree F temperature rise is only capable of delivering 20 btu's per pound of water to the load. For the same heating requirement, a mass flow rate of water from a hydronic boiler with a 20-degree F temperature rise needs to be 50 times greater than from a steam boiler. This is a critical factor in understanding the development of first-to-market Rainmaker condensing economizer technology.

Boiler economizers have been nearly exclusively utilized on steam boilers. Consider for example a requirement for 800 HP of required heating. As horsepower is a measure of output 800 HP equates to 27.6 mmbtu. The nominal mass flow rate of water through an 800 HP steam boiler is 27,600 pounds per hour (pph) with each pound of steam generated delivering 1,000 btu's. A hot water boiler limited to a 20-degree F temperature rise must flow 1,380,000 pph of water to be able to deliver the same 27.6 mmbtu. A century of boiler economizer technology had been focused on the water flow rates associated with steam boiler operation. Steam boiler economizers cannot accommodate the water mass flow rates associated with hydronic boilers. These limitations in conjunction with the reality that conventional hot water boilers were already more efficient than steam boilers meant there was never a need for a hydronic boiler economizer.

The concept of utilizing condensing hydronic economizers is not entirely new. Early in the development of condensing boilers some manufacturers converted their conventional boiler offerings into condensing options by adding a secondary condenser to the exhaust. These heat exchangers were small and specifically designed for a mass-produced product never intended to be stand-alone products capable of being built to large sizes and fitted to both new and existing boilers. Around 2010 Boilerroom Equipment Inc recognized an opportunity for a first-to-market condensing hydronic boiler economizer that would enable conventional steam and hot water boilers to be able to perform in a condensing environment. Over the years BEI has refined the Rainmaker into an ASME Code heat exchanger with unmatched capabilities. All wetted surfaces are supplied of 316 stainless steel with the heart of the heat exchanger being a hybrid 316 stainless tube with corrosion resistant aluminum fins. A modular design, the Rainmaker enables every design to be custom selected to the unique requirements of each project. BEI recognized no two boilers are alike and designed a new generation of heat exchanger consisting of three-dimensional pre-engineered heat exchanger blocks that could be configured to optimize the design requirements. Supporting the thousands of permutations, the modular approach presented required the creation from scratch of the industry's most advanced heat exchanger design software. The "Bruce" software as it is known was conceived and programmed solely by BEI to support the great number of variables that make up the Rainmaker and has no known equal in the global boiler market. A boiler fitted with a Rainmaker can meet the same efficiencies of any condensing boiler given identical operating parameters. A simple exhaust gas bypass, the only moving part on a Rainmaker, may be utilized when firing #2 fuel oil to protect it when the boiler is required to fire oil.

The concern always mentioned when considering a hydronic condensing economizer is the potential impact on the non-condensing boiler. For high pressure steam systems there is no other considerations needed as the temperatures are almost always well above any condensing concern. When installed on a hot water boiler a basic keep-warm loop using on a circulation pump and control valve is utilized to protect the boiler. A conventional hydronic boiler installed in a conventional primary-secondary arrangement will continue to operate at non-condensing temperatures. Some of the hot supply water is simply blended into the return exiting the Rainmaker to ensure the boiler is shielded from condensing or thermal shock. For systems that require a specific supply temperature the use of a three-way valve blends some of the cold return into the heated supply to control the final supply water temperature delivered to the plant. Such systems are typically integrated into conventional hot water boilers already to protect the boiler during start-up and high turndown scenarios. As a circulation pump is already required for a primary-secondary piping arrangement the only additional cost introduced by the Rainmaker is a three-way valve and its logic control.

Condensing boilers have been engineered for optimum performance while condensing, however most facilities can only take advantage of the colder water temperatures required for the increased efficiency when the outside temperatures are not excessively cold. During times of high heating demand the supply temperatures must increase, quite commonly to temperatures above the dew point the removes the ability to condense. As most condensing boilers are optimized for condensing their efficiencies plummet during high temperature operation. The advent of the hydronic economizer concept allows the system to realize optimum efficiencies at any operating temperature. Far too often condensing boiler operation is viewed as a snapshot in time when their performance is most advantageous. The heating surface of a Rainmaker is designed for both a sensible and latent heat exchange within the heat exchanger bundle. When the return water temperatures are too high to condense the Rainmaker will operate in a sensible recovery mode same as any conventional economizer. This means any boiler equipped with a Rainmaker will provide the highest possible efficiencies at all operating temperatures and firing rates.

Because the Rainmaker is an external condensing heat exchanger rugged, long-lived, reliable, and relatively inexpensive industrial steam boilers can once again be utilized in the design of hydronic heating systems. While the boiler itself may only be 82% efficient, the exhaust gases that in the past were wasted to atmosphere now pass into a condensing Rainmaker. The same flow and temperature of the return water to a condensing boiler is now sent into the Rainmaker and is used to condense the steam boiler exhaust no different that the exhaust that would be condensed in a condensing boiler. The now hotter return water exiting the Rainmaker would go into the steam heat exchanger to bring it to the same supply temperature as a condensing boiler. The Rainmaker allows for the replacement of a 95% efficient condensing boiler with an 82% efficient steam boiler paired with a Rainmaker sized for a 13% efficiency improvement resulting in the same final efficiency any condensing boiler would achieve. End users need only have operator training and spares for a single type of boiler resulting in simpler operation and easier, lower cost, long term serviceability. Since the Rainmaker only operates as an efficiency improvement device should the economizer be required to be removed from service the rest of the system can operate normally at no risk of loss of heat for the facility.

As the majority of condensing boilers tend to be under 6 mmbtu, large heating loads require multiple boilers. It has not been uncommon to see boiler rooms with upwards of ten or more of these smaller condensing boilers. Each one of them requires utilities to be supplied, need their own flue, each need to be installed and serviced, etc. As the capacity of the Rainmaker is near limitless for most industrial heating applications few and larger industrial boilers can be installed with a common Rainmaker to meet the same efficiencies of the multiple condensing boilers and do so at staggering reduced costs. Higher circulating water mass flow rates require larger pipes to adequately move the water. Multiple condensing boilers require the installation of a network of piping and valves at great expense to service so many small individual boilers. A common condensing economizer for multiple conventional boilers need only require the installation of the common primary supply and return loop to the Rainmaker and then the instantaneous heater. Only the boiler exhaust ducts need to be directed to the condensing economizer and exit to a common flue to atmosphere. Because the exhaust from the boilers is relatively hot there is no need for the expensive stainless-steel duct that a condensing boiler would require until after the Rainmaker. It is not uncommon to hear of savings of half of project costs when considering the conventional boiler paired with a Rainmaker approach.

As was stated earlier the laws of thermodynamics are no different for a packaged condensing boiler then they are for a conventional steam or hot water boiler paired with a condensing economizer. Condensing hydronic economizer-based heating systems provide the same efficiency as any condensing boiler in identical service and do so at lower acquisition, installation, and long term operating expense. Such a system would be impossible to realize without the willingness to develop a modular high mass flow heat exchanger.

As the vision behind the years of development of the Rainmaker technology, having engineered the heat exchanger and written all of the supporting code, I certainly acknowledge my bias however I am convinced the development of this revolutionary type of condensing economizer is an industry-changing concept that represents one of the greatest evolutions to hot water heating since the development of the condensing boiler itself. On behalf of the dedicated engineers and fabricators at Boilerroom Equipment Inc that worked to bring this concept to reality we all sincerely appreciate your consideration of what we collectively have created.

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