PAPER • OPEN ACCESS

Pipe Designs of the Closed Feedwater Heater Rankine Cycle Power Plant

To cite this article: Mingcheng Li *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **615** 012065

View the article online for updates and enhancements.

IOP Conf. Series: Earth and Environmental Science **615** (2020) 012065 doi:10.1088/1755-1315/615/1/012065

Pipe Designs of the Closed Feedwater Heater Rankine Cycle Power Plant

Mingcheng Li[1, a, †], Hongtao Luo[1, b, †], Maolin Peng[1, c, †]

[1]Swanson School of Engineering, University of Pittsburgh, PA, United States.

[a]MAP410@pitt.edu

[a]MIL154@pitt.edu; [b]HOL53@pitt.edu; [c]MAP410@pitt.edu

[†]These authors contributed equally.

Abstract. How to lower global energy consumption and improve energy conversion efficiency remains a major challenge in the fields of science and technology. Scientists have done tremedous work to save energy. For example, scientists have improved and designed the different parts of heating systems to make it approach the thermal idealized cycle, in order to increase the waste-heat utilization rate and convert heat into other forms of useable energy. After thorough study of the Closed Feedwater Heater (FWH) Rankine Cycle power plant, this paper shows two possible designs to increase energy efficiency: the Cylinder and Sphere Feedwater Heater, and the Pipeline Mini Turbine. Compared with the old system components, they convert steam's kinetic energy into usable electricity or other forms of energy and reduce the waste of energy caused by temperature differences and circulations. As a result, they increase the heat transfer efficiency between water and steam in the feedwater heater and save more money because of the reused component.

1. Introduction

The rate of depleting fossil fuel reserves and global climate change have been global concerns. Under the circumstances, countries all over the world are trying to lower their emissions and energy consumption. So scientists must consider ways to develop power generation technologies in order to improve energy conversion efficiency considerably. For example, in conventional thermal power plants, there are about two-thirds of the energy of the input fuel is wasted in stacks and cooling towers [1-3]. Lots of similar instances show that in many high-temperature applications or energy-intensive processes, energy utilization becomes inadequate, and significant energy losses do occur. The most important causes are: (1) faulty designs, (2) a faulty maintenances, (3) a faulty operations, (4) unsuitable operating temperature and environment, and (5) lack of efficient energy recovery [4-5].

Nowadays, scientists have designed many technologies, power plants, and other apparatus to improve efficiency and output power. Tri-generation is an efficient way of maximizing the utilization of energy. A waste heat recovery system or waste heat recovery unit (WHRU) is a newly designed energy recovery heat exchanger [4]. The combined cycle power plant (CCPP) and S-CO2 (Supercritical-CO2) coal-fired power plant are promising technologies for efficient and clean utilization of power generation [6-8]. Also, to get closer to the Carnot cycle, scientists try to optimize four main parameters: the temperature of heat source, stroke, mean effective pressure, and the engine frequency [5].

IOP Conf. Series: Earth and Environmental Science **615** (2020) 012065 doi:10.1088/1755-1315/615/1/012065

In this paper, we focus on waste-heat utilization [9] and decentralized systems [4] [10]. We use the Closed Feedwater Heater (FWH) Rankine Cycle power plant as our model and propose two design schemes based on the decentralized system. The first is the Cylinder and Sphere Feedwater Heater. It uses waste heat of steam to preheat incoming water by increasing the pipe contact area. The second design is the Pipeline Mini Turbine. It uses turbines to collect the kinetic energy of steam passing through the pipe, which can then be used elsewhere. These two designs can utilize waste-heat well and improve energy conversion and recycling. At the same time, decentralized systems help operators to better maintain and operate the equipment.

2. Design of the Closed FWH

2.1. The Cylinder and Sphere Feedwater Heater

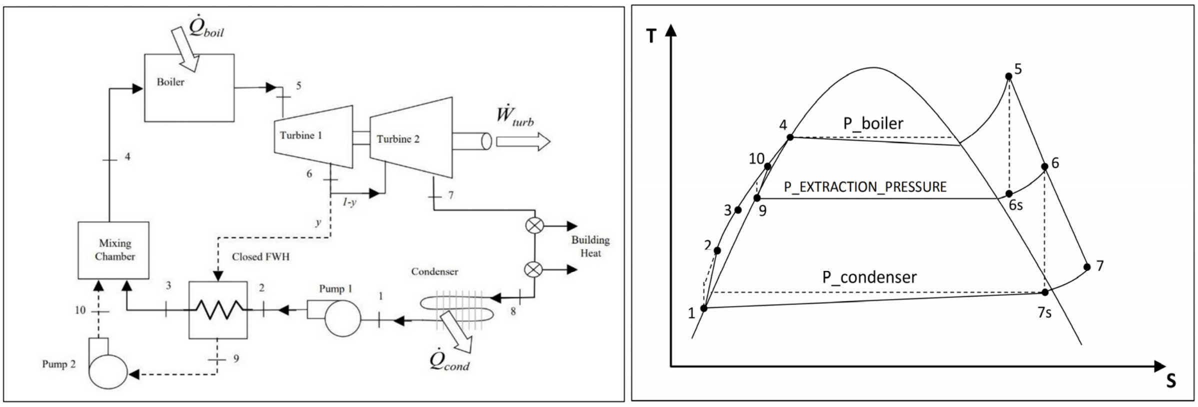

Figure 1. Idealized Model and T-s Diagram of closed FWH Rankine Cycle

In this part, the Cylinder Feedwater Heater and the Sphere Feedwater Heater will be introduced. Consider a regular thermal power plant using closed FWH (Feedwater Heater) as its heat exchanger (Figure 1). In this thermal power plant (modified as a Rankine Cycle), closed FWH, working as a heater system, is used to preheat the water that is delivered to the boiler to generate steam. Based on the assumption that no pressure drops among these devices and the steam state at position 1 are saturated liquid, we can draw the T-s diagram of this idealized cycle (Figure 1). As can be seen, the closed FWH allows the water to be heated up to the saturated temperature and therefore increase the thermodynamic efficiency of the system.

However, although the closed FWH is used widely, much energy become wasted because of the temperature differences between environment, loss in the process of cycling, or other aspects. Therefore, to utilize those waste-heat, we consider several decentralized systems to roughly increase the energy utilizing efficiency. First, utilize the released heat in the process of cycling. For example, as we model in Figure 1, we can set a device station that transfers the superfluous heat to nearby buildings as their heating source in winter. After rough calculation, we find out that if we utilize superfluous heat for building heat, we can reduce the cost of this power plant by more than 1 million dollars per year. In detail, the most waste of energy occurs in the process of cycling especially in the pipes, mixing chamber, and feedwater heater. First, to increase the heat transfer efficiency between water and steam in the feedwater heater, we design two devices. The first one is a cylinder heat exchanger surrounded by circles of steam pipe (the whole system is enclosed in heat insulation materials) (Figure 2).

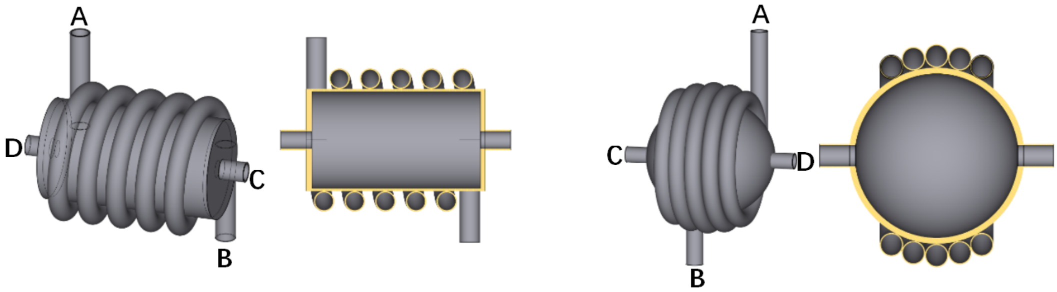

Figure 2. The Cylinder Feedwater Heater & the Sphere Feedwater Heater

The second device is a sphere heat exchanger surrounded by pipes (Figure 2, the figure is is not accurate limitation). In both cases, extraction steam flow in through pipe A and flow out through pipe B, while condensed water flows in through pipe C and flow out through pipe D. When condensed water flows into the cylinder, with the cross-section area increasing, the velocity of fluid decrease; because the steam and condensed water flow in opposite direction, the heat transfer between them is maximized. Comparatively, the sphere device has a greater efficiency because the surface area of the sphere is the greatest on the same scale. Except for high efficiency, this design is also beneficial in expense, because the only thing we need is the pipe and the heat insulation materials in the surrounding environment. These two devices can be used in other components in the cycle. For example, when condenser transfers superfluous heat to the surrounding, we can use the waste heat to heat air then deliver these high-temperature air to the mixing chamber and use these two devices to pre-heat the mixing water before entering the boiler. In this case, water mix in the mixing chamber (the cylinder part or sphere part in Figure 2) and air flow in through A and flow out through B.

2.2. The Pipeline Mini Turbine

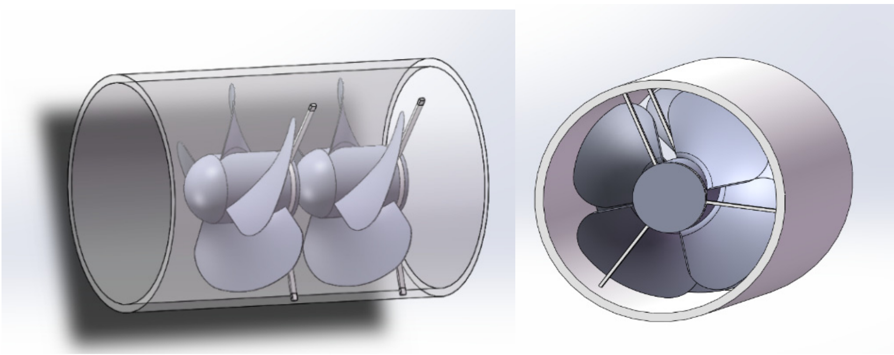

Figure 3. The Pipeline Mini Turbine

Figure 3 shows a new design called the Pipeline Mini Turbine. Before providing more details, it is necessary to return to Figure 1. After the flow going through the turbines, there is kinetic and thermal energy remained in the flow which could be generated for better efficiency of energy utilization. For instance, the water comes from turbine 1 in Figure 1 with high pressure could accelerate the flow in pipe 6. However, this portion of the energy is hard to generate in the central system which is turbine 1. Besides, the marginal benefit is low for plants to spend money to change the structure of the turbine only for a small portion of unutilized energy.

Under the circumstances that the central system is too sophisticated and costly to change, the change of the decentral system could be a better choice. The change of pipeline could be an excellent decentral system for generating wasted energy. Initially, the flow has to go through a pipeline from turbines to feedwater heater, which means that energy flow in the pipeline as well. Moreover, the upgrade of the pipeline will not cost as much money and time as the change of turbines.

The pipeline mini turbine in Figure 3 is a solution the wasted energy utilization. The primitive of the design has four fans. There is a permanent magnet in the head for the stator cutting magnetic lines to generate electricity. Therefore, it could generate energy by transforming the kinetic energy of flow into electric energy. The pipeline mini turbine could be customized according to the radius of the pipeline and fixed by a ring tripod inside the pipeline. The design is cheap and flexible to install in the pipeline, which could make energy collection cost-efficiently. When the water flows into the pipeline with high speed from turbine 1 in Figure 1, the mini turbine will generate energy from the flow so that the wasted energy could be transformed into electric energy. On the other side, the change in the pipeline does not require a lot of money and time. Once installed, the utilization of wasted energy could be higher. However, the design is rough and ideal. The actual design requires more sophisticated information about the size of the fan, and the interval for each pipeline mini turbine so that the energy utilization and benefit could be optimized.

3. Conclusion

In today's world, the energy consumption problem is serious, so it is urgent for mankind to reduce energy consumption in all aspects and increase energy conversion efficiency. As for FWH, how to design a more efficient pipeline is still rarely discussed. In this paper, we propose two designs to solve this problem. The first design is the Cylinder and Sphere Feedwater Heater, which can reduce the waste of energy caused by temperature differences and circulations. Using excess energy to warm water can reduce costs and save energy. In addition, another design is the Pipeline Mini Turbine. The design converts steam's kinetic energy into usable electricity or other forms of energy by adding fan systems to the pipes. In conclusion, the complaint about thermal energy saving is not uncommon, but with the new feedwater heater and mini turbine , many existing problems can be solved.

References

[1] Khandelwal N, Sharma M, Singh O, et al. Recent Developments in Integrated Solar Combined Cycle Power Plants[J]. Journal of Thermal Science, 2020, 29(2): 298-322.
[2] Hirvonen J, Kayo G, Hasan A, et al. Local sharing of cogeneration energy through individually prioritized controls for increased on-site energy utilization[J]. Applied energy, 2014, 135: 350-363.
[3] Kılkış B. Development of an Exergy-Rational Method and Optimum Control Algorithm for the Best Utilization of the Flue Gas Heat in Coal-Fired Power Plant Stacks[J]. Energies, 2019, 12(4): 760.
[4] Narayanan C M, Pramanick T. Computer aided design and analysis of regenerators for heat recovery systems[J]. Industrial & Engineering Chemistry Research, 2014, 53(51): 19814-19844.
[5] Toghyani S, Kasaeian A, Hashemabadi S H, et al. Multi-objective optimization of GPU3 Stirling engine using third order analysis[J]. Energy Conversion and Management, 2014, 87: 521-529.
[6] Mohan G, Dahal S, Kumar U, et al. Development of natural gas fired combined cycle plant for tri-generation of power, cooling and clean water using waste heat recovery: techno-economic analysis[J]. Energies, 2014, 7(10): 6358-6381.
[7] Oko C O C, Njoku I H. Performance analysis of an integrated gas-, steam-and organic fluid-cycle thermal power plant[J]. Energy, 2017, 122: 431-443.
[8] Chen Z, Wang Y, Zhang X, et al. The energy-saving mechanism of coal-fired power plant with S–CO2 cycle compared to steam-Rankine cycle[J]. Energy, 2020, 195: 116965.
[9] Alexe F N, Darie G, Cenuşă V E, et al. Recovery of waste heat from generator into the water preheating circuit, at steam thermal power plants[C]//2015 9th International Symposium on Advanced Topics in Electrical Engineering (ATEE). IEEE, 2015: 603-608.
[10] Akbari K, Nasiri M M, Jolai F, et al. Optimal investment and unit sizing of distributed energy systems under uncertainty: A robust optimization approach[J]. Energy and Buildings, 2014, 85: 275-286.