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Impact of the Reheating Cycle on the Rankine Cycle Efficiency and Important in Thermal Applications

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Abstract: The goal of reheating is to prevent the steam from carrying extra moisture when it expands in a turbine's final phases of expansion. As a result of excessive moisture, the turbine blades deteriorate. Steam turbine efficiency may be enhanced by lowering the condenser pressure, raising the boiler pressure, or by using the reheat cycle and regenerative cycle, amongst other methods. There are numerous phases of expansion in various turbines in the reheat cycle. This condition of super-heated or dry saturated vapor is reached after the initial expansion stage. In the boiler, the vapor is warmed before being transported to the turbine for the next step of expansion. Both the reheat cycle and the regeneration cycle may increase the Rankine cycle's performance and efficiency. The steam entering the turbine may be enhanced by enhancing its thermodynamic qualities. Enhanced pressure leads in an increased expansion ratio in the beginning. However, when the expansion nears its finish, damp steam may be seen. This is owing to the steam's higher moisture content. This isn't a good thing since it causes the turbine blades to wear down faster and eventually lose their efficiency, reducing the nozzle and blade's performance. These issues may be solved by using the reheating cycle. An ideal cycle and a real-world cycle are discussed in this study to compare their heat rates and steam flows, as well as some fundamental techniques.

Keywords: Reheat; Regeneration of steam; Thermal efficiency

INTRODUCTION

Mechanical stresses grow at a greater rate than the pressure increase due to the increased temperature in the boiler, hence increasing the number of reheats is necessary. As a result, only two reheats are allowed in a single reheat cycle. High-pressure turbines and low-pressure turbines are the two main kinds of turbines. and the Cycles of Reheating [1].As thermal efficiency improves, more power can be extracted from a machine of a given physical size, causing steam pressure and temperature to rise continuously at the turbine intake. Pressures of 1,800 to 2,400 psi and temperatures of 1000 to 1050F are typical on big units of 100,000 kilowatts or more. In one example, 2,400 psi-1100F was used. It's now in operation to heat up 4,500 psi-115F with a double-reheated reheat to 1050F, and a new one for 5,050 psi-1200F with a similar double-reheated reheat to 1050F will be built soon. The development of more cost-effective and readily available high-strength materials seems to be required before temperatures may rise over 1200F [2-3].

Certain large steam plants designed for the use of fuel will employ saturated steam without additional heating or cooling owing to reactor temperature constraints[4]. At low pressure, steam channels and/or crossover connections between turbine casings will need moisture extraction devices to prevent severe erosion. Using such technology, it seems that the moisture content may be reduced to values that haven't been reached before. Reheating occurs when steam is extracted from the turbine and heated in the boiler furnace by flue gases, as shown in Figure.1 [5].

Reheating is mostly used to alter the thermodynamic parameters of the exhaust steam from the first turbine. Steam's moisture content drops as it moves through the turbine's stages, resulting in a drying effect. It is important to note

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that the dryness percentage of steam should not go below 0.88. Additionally, the amount of particular steam used is down [6].

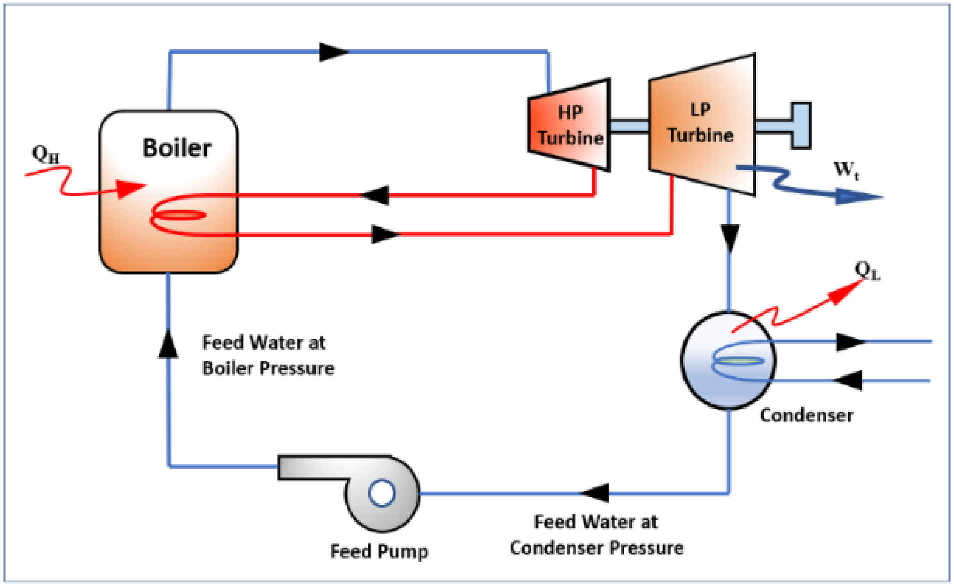


FIGURE 1. A Schematic Diagram of Reheat Cycle

The reheat pressure of steam and the initial pressure of steam are both regarded to be 0.4, which leads in an improvement in thermal efficiency [7]. This cycle begins with a partial expansion of steam, which is then reheated before returning to the turbine's lower pressure segment. The heat rate of the turbine is reduced by around 5% when it is reheated. An increase in thermal efficiency of 60% and a 40% increase in thermal gain are the most likely outcomes, although there are many other factors at play. However, warming cycles are restricted in practise due to economic losses and the intricacy of the plant cycle as seen in Figure 2 [8].

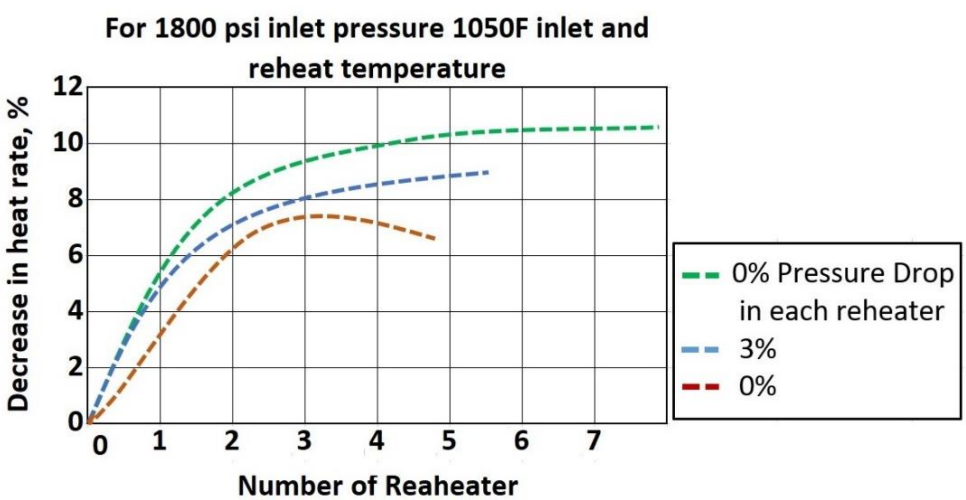


FIGURE 2. Benefits approximately resulting from Reheating

Using the same beginning steam thermodynamic conditions as before the reheat cycle, the throttle steam flow rate is reduced by 17 percent, and the condenser steam flow rate is decreased by 13 percent [9].It is common for the reheat pressure to be 20 to 30 percent higher than the initial pressure in practise. To ensure that the steam supply to the turbine is not interrupted in the case of a rapid decline in demand, it is necessary to have fast-closing valves, such as intercept valves, installed [10]. The speed governors on the turbochargers control the operation of these control valves. The employment of a second set of valves to bypass this amount of steam to the condensers may be necessary in extreme circumstances, especially if the rotor inertia of the turbine and generator is very low [11].

LITERATURE REVIEW

The exergy and energy consumption of a steam power plant have been thoroughly investigated to the greatest degree possible. The HYSYS [12] programme is used to conduct the investigation of the regenerative Rankine cycle with various heaters. It has been discovered that reheating and regeneration of the Rankine cycle may boost the thermal efficiency of a plant [13-14].It has been shown that the steam power plant's regeneration cycle is more efficient than the steam power plant's reheat cycle, based on comparisons made using the c program's thermal efficiency calculations using various process parameters.The heat from the condenser is utilised to heat the boiler water in order to enhance the thermal efficiency of the regeneration cycle overall. The Absorption Heat Transforms Technique is used to carry out this procedure, and it is very effective[15]. It has been discovered that increasing the number of feed water heaters in a regenerative Rankine cycle may enhance the thermal efficiency of the cycle [16]. The water rate of the turbine has been enhanced to reduce the steam turbine's energy consumption. Efforts have been made to reduce the amount of energy needed for growth by using innovative technology. Steam turbine plant reheat and regeneration cycles [17-18] have studied the quality of steam production irreversibility.After examining the environmental pollution variables, researchers discovered that the standard Rankine cycle uses more fuel than necessary, requiring the usage of fossil fuels in order to decrease pollution [19].Thermal characteristics of steam have been studied using a MATLAB software that is focused on the turbine's inlet and outlet temperatures and pressures. Analysis of exergy losses has also been done [20]. For several cycles involving different organic fluids, thermodynamic analysis has been performed and it has been shown that reheating in conjunction with a regeneration facility is the most cost-effective option [21].

EXPERIMENTAL PROCEDURE

Multistage turbines have the benefit of recouping some of the energy that is lost in the first stages of operation. Steam enthalpy behind the stage rises as a result of energy losses in a stage. As a consequence, the temperature of superheated steam rises, and the dryness percentage of wet steam decreases [22-23].

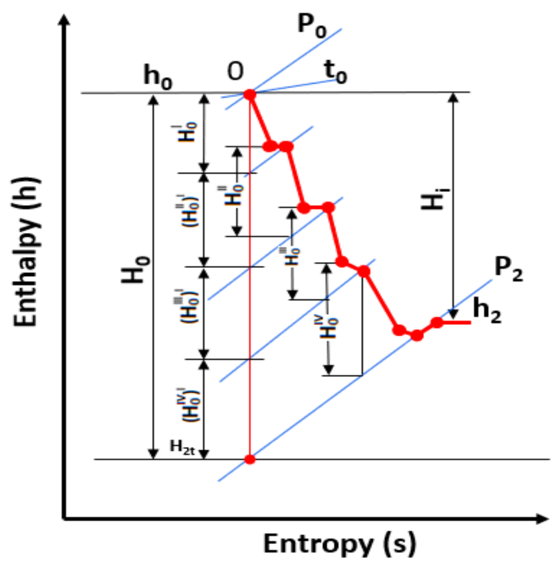


FIGURE 3. h-s Diagram of Multi-Stage Turbine Steam Expansion

As a consequence, the temperature of the steam increases. As the dryness percentage of the steam's temperature rises, the stage's heat losses increase in contrast to those computed along the main isentropic of optimum steam expansion, as does the stage's heat loss. In Figure.3.

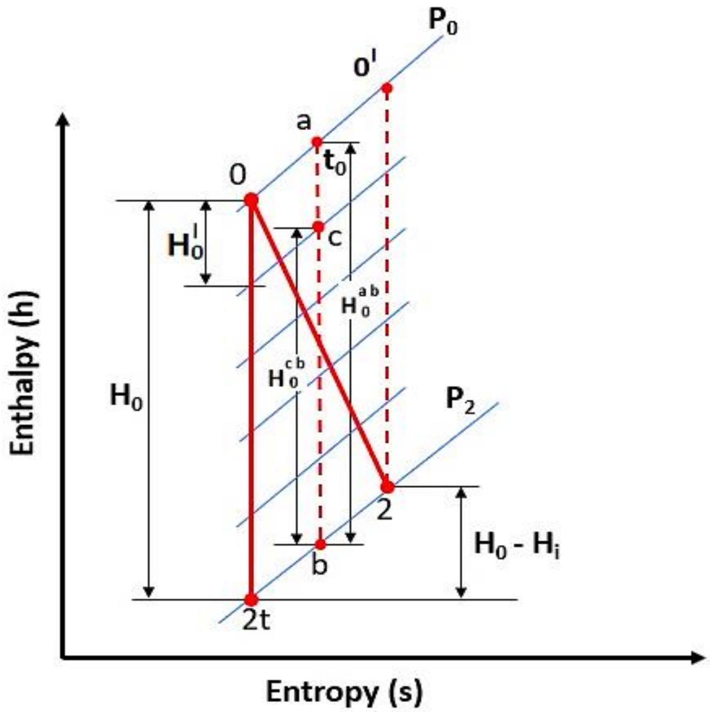


FIGURE 4. h-s Diagram for Developing the Reheat Factor Formula

Isobars in the h-s diagram are known to diverge toward increased entropy, resulting in this increase in heat drop. To put it another way, the heat losses of turbines are phases.

$$\boldsymbol{H_0^I, H_0^{II}, H_0^{III}}$$

addition, their aggregate is bigger than a turbine's isentropic loss in heat H0 along its primary path i.e.

$$\sum_{i=1}^{z} \boldsymbol{H_0^i - H_0 = Q} \tag{1}$$

In a multistage turbine, the amount of energy available in each stage is increased by the amount of heat that is recovered from the stages' energy losses. Figure.5 shows a multistage turbine with the same efficiency (η) for each stage.

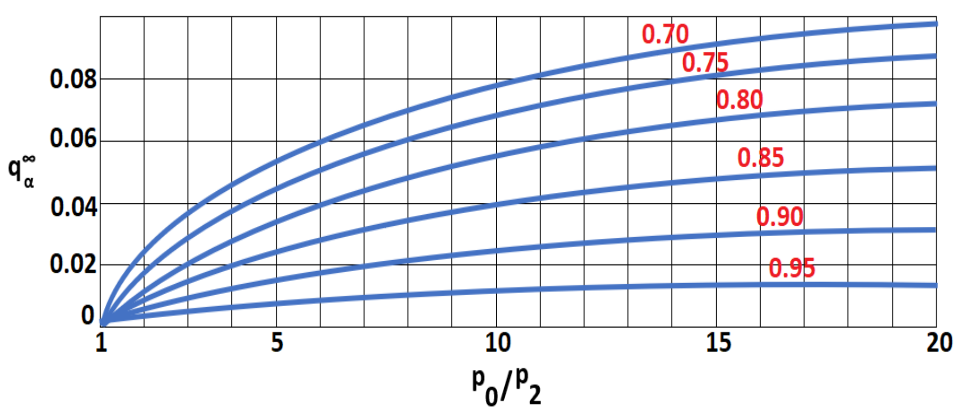


FIGURE 5. Turbine Reheat Factor for an Infinite-Stage Machine with k=1.3

$$\eta_{ri} = \frac{H_i}{H_0} = \frac{\sum_{i=1}^{n} H_i^n}{H_0} = \frac{\sum_{i=1}^{n} H_0^n \eta_{ri}^{si}}{H_0} = \eta_{ri}^{si} \frac{H_0 + Q}{H_0} \tag{2}$$

(or)

$$\eta_{ri} = \eta_{ri}^{si}(1 + q_t)$$

Where $q_t = \frac{Q}{H_0}$ is derived from the formula above as the heating factor, Heat recovery (reheating) improves the internal efficiency of a turbine by increasing its operating temperature. The reheat factor may range from 0.02 to 0.10, depending on H0, the number of stages, and the effectiveness of the system. When working with a known h-s diagram of steam expansion and a predetermined number of stages, the reheat factor may be calculated using formulas (1) and (2). (2). In order to determine how much heat has been recovered, one of them use the h-s diagram depicted in Figure 4.
If the turbine operates in the manner shown in line 0-2, the total quantity of heat lost throughout the duration of the process is likely to lie somewhere between the numbers computed in sections 0-2t and 0'-2. According to Section 0'-2, if subsequent stages' energy losses are recovered, the steam temperature before the first stage increases.
The isentropic a-b line, which crosses through the midpoints of sections 2t-2 and 0-0' and represents the entire energy loss as it climbs practically linearly from stage to stage, illustrates the true sum of heat decreases. This formula may be used to calculate the reheat factor of a turbine with an unlimited number of stages.

$$q_t^{\infty} = \frac{H_0^{ab} - H_0}{H_0} \tag{3}$$

Let's look at the equation for the decrease in available heat:

$$H_0 = \frac{k}{k-1} R T_0 \left[1 - \left(\frac{p_2}{p_0}\right)^{k-\frac{1}{k}}\right] \tag{4}$$

$$= \frac{k}{k-1} p_0 v_0 \left[1 - \left(\frac{p_2}{p_0}\right)^{k-\frac{1}{k}}\right]$$

Where $v_0 = v^n x$ (for wet steam).

$$Q_{\infty} = H^{ab}_0 - H_i = (1 - \eta_{ri})$$

Following these steps, the recovered heat may be determined as follows:

$$Q_{\infty} = \frac{k}{k-1} R (T_{0a} - T_0) \left[1 - \left(\frac{p_2}{p_0}\right)^{k-\frac{1}{k}}\right]$$

$$\text{Since } T_{0a} = T_0 + \frac{(H_0 - H_1)}{2c_p} \text{and} \quad H - H_i = (1 - \eta_{ri}) x\, H_0$$

$$q_t^{\infty} = \frac{A}{T_0} (1 - \eta_{ri}) H_0 \tag{5}$$

Take, for example, the case when A has an isentropic exponent of k and R is the gas constant. Formula (5), which may be used for an endless number of stages, is helpful for calculating steam expansion when utilising the h-s diagram. This formula may be modified to make use of the ideal gas equations if that is what is needed. Figure.5

$$q_t^{\infty} = A' (1 - \eta_{ri}^{si}) \left[1 - \left(\frac{p_2}{p_0}\right)^{k-\frac{1}{k}}\right] \tag{6}$$

The reheat factor diminishes as a result of the fact that heat recovery in a limited number of turbine stages does not compensate for the heat loss of the first stage. Because of the restricted number of phases, the quantity of heat that can be recovered Q reduces to the level depicted in Figure 4.

$$Q = H_0^{cb} - (H_0 - H_0') \tag{7}$$

This means that if we have the same reduction in temperature in all phases, we get the same result.

$$H_0^{cb} = H_0^{ab} \frac{z-1}{z} \text{ and } H_0 - H_0' = H_0 \frac{z-1}{z}$$

In this case, the reheat factor may be expressed as follows:

$$q_t = \frac{(H_0^b - H_0^1)^{z-\frac{1}{2}}}{H_0^1} = q_1^{\infty} \frac{z-1}{z} \quad (8)$$

In practise, the formula is generally changed to something like this:

$$q_t = k_t(1-\eta_{ri})H_0 \frac{z-1}{z} \quad (9)$$

In the case of a group of stages operating in the superheated steam zone, K_t is considered to be 4.8×10^{-4}, in the case of a group of stages operating in the wet steam zone, and in the case of a group of stages operating partially on superheated steam and partially on wet steam, K^t is considered to be $3.2\text{-}4.3 \times 10^{-4}$. The kilojoules per kilogramme (KJ/kg) value for kt correlates to the value of H_0 in terms of energy.

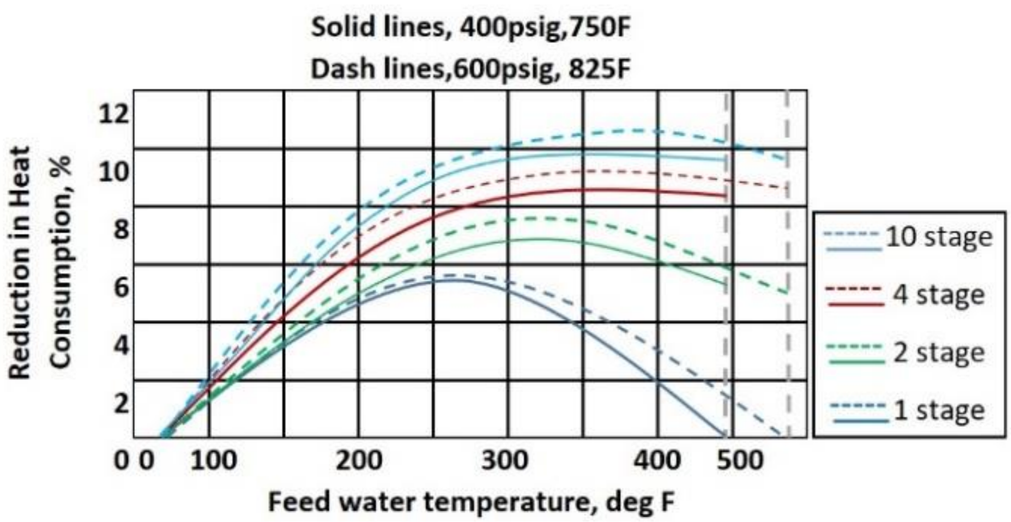
RESULT AND DISCUSSION

When it comes to large-scale, high-capacity power plants, reheating is the most popular method. The ideal cycle and the realistic cycle are compared. Mixing heaters are utilised in the optimum cycle, with the exhaust from each pushed back in. When using a practical cycle, however, closed heaters are preferred since the top heater is pumped dry while the lower heater is cascade dried.

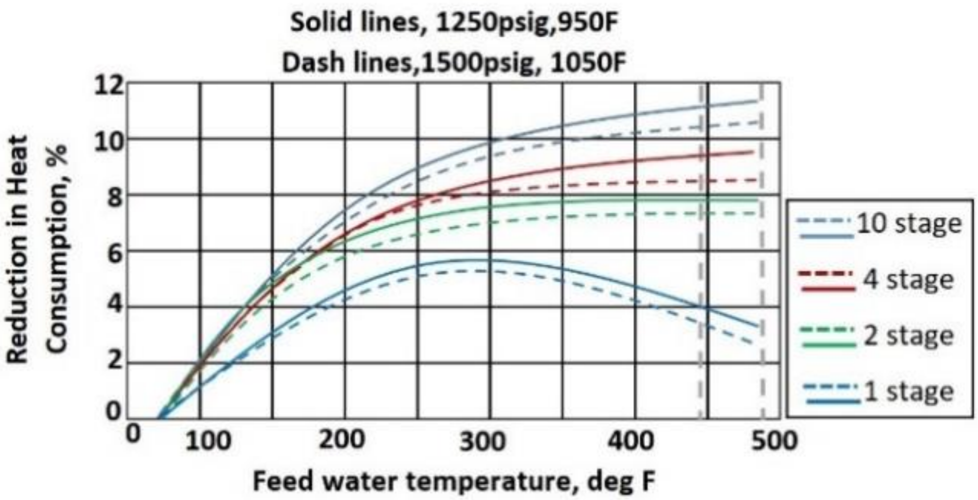
TABLE 1. The Steam Is Dry Saturated and The Exit Pressure is 0.04 bar.

	Pressure	Efficiency	Dryness at exit
Super-heated to 600°C	160bar	45.3	77.2
	350bar	46.8	70.8
Super-heated and reheat to 600°C	160bar	46.8	95.4
	350bar	48.5	87.1

It's not uncommon for there to be a 1 ½ % difference between these two cycles. Figures.7 and 8 show the heat rate decrease and steam flow rise rates for the two cycles, respectively.



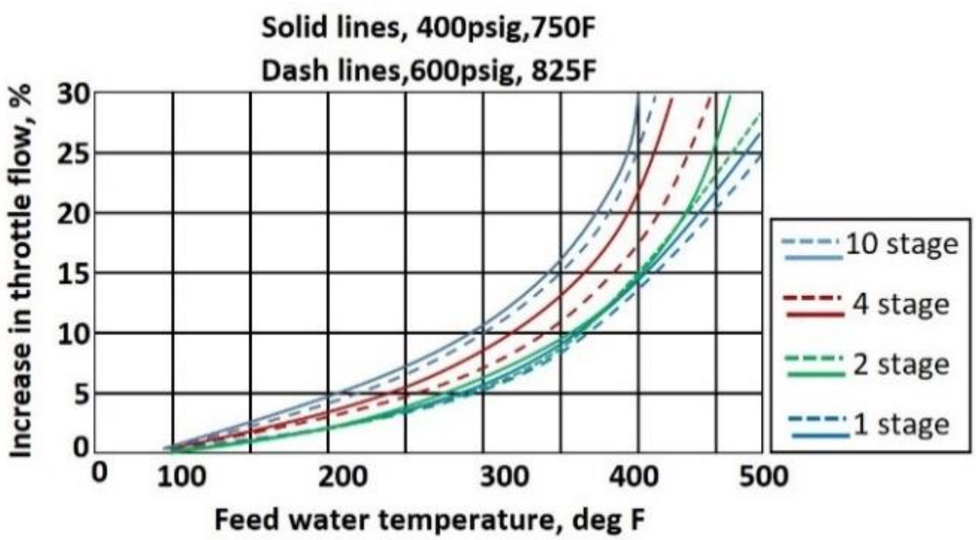
(a)



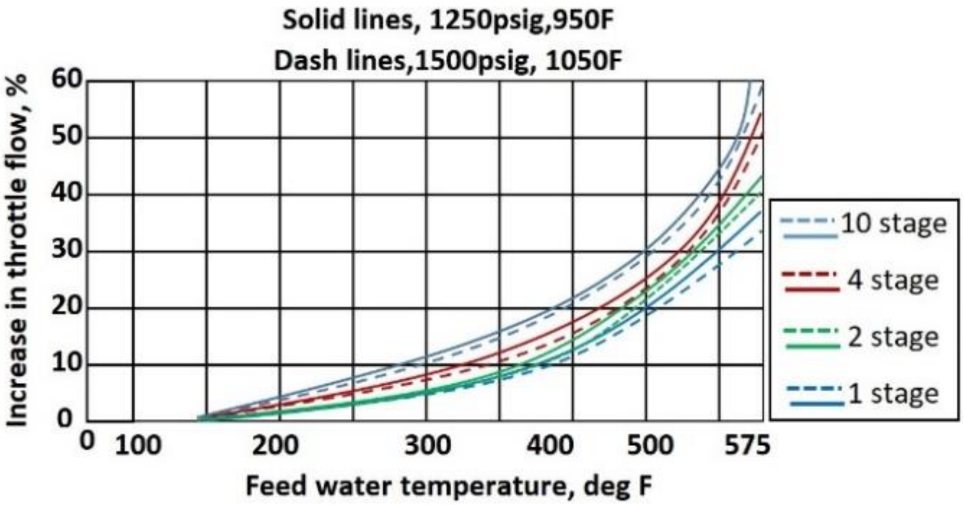
(b)

Figure 6. (a) & (b) Heatrate reduction is achieved by the employment of an ideal cycle with a back pressure of one inch of mercury.

Its efficiency is increased by raising the average temperature of heat receipt, which is achieved by reheating the regenerative steam power cycle. Because reheating uses superheated steam with a higher temperature differential than the feed water heater, the irreversibility of feed water heaters is increased even though there is a gain in efficiency as a result of the reheating process. The current invention modifies the standard reheat regenerative steam cycle to reduce the irreversibility of the regenerative process.In addition to the usual reheating, the innovation employs reversible reheating, which results in fewer temperature fluctuations between feed water heaters than the standard cycle. It is necessary to conduct a comparative study between the conventional reheat regeneration cycle and the newly designed cycle.



(a)



(b)

FIGURE7. (a) & (b) When employing the ideal cycle with a 1-inch Hg back pressure, the rate at which steam flow must be raised in order to retain the same power output must be calculated.

In order to avoid making a provision for the loss of feed-pump power, which is about two-thirds of the net output's power, it is assumed that the power lost will be recovered in the system. Figure 7 illustrates that as the feed-water temperature declines, the heat rate reduces for a variety of starting pressures and temperatures, as well as for a 1-inch Hg back pressure.

CONCLUSIONS

With the same pressure, temperature, number of reheating processes, and feed water heaters as previously, the researchers discovered a 2.5% efficiency gain. Besides that, the new cycle reduces the mass flow rate that must be warmed often by up to 50% while retaining the same output power. Among other advantages, pressure drop and heat loss are decreased. Due to these advantages, we may use more reheating stages of the new cycle to achieve the same pressure drop and heat transfer losses of the reheater pipes as the standard cycle. Furthermore, because feed water heaters normally run at two-phase temperatures, the new cycle's heat exchangers perform better than the standard cycles. As a result of this practical advantage, the new cycle's heat exchangers are smaller than the old cycles.

- Thermal power station efficiency and blade efficiency are both improved by reducing steam moisture content and increasing the dryness percentage of the steam during a reheating cycle.
- By using the reheating cycle, you may increase overall cycle efficiency while simultaneously shrinking the size of the plant.
- Theoretically, reheating may be repeated an unlimited number of times, but in practise, this is impossible due to the financial costs and the intricacy of the plant cycle.

REFERENCES

1. Subramanyam Pavuluri, N. Srinivasa Rajneesh, Ch. Ashok Kumar, and S. Udaya Bhaskar, "Effect of reheating cycle on efficiency of Rankine cycle and its practical significance", AIP Conference Proceedings 2358, 110009 (2021) https://doi.org/10.1063/5.0058047
2. ValenicaOchoa,Garcia Sierra, Diaz Manotas D "Energy and Exegetic Analysis of Regenerative Rankine cycle with feed water heaters" International Journal of Chem Tech Research (2017):36-44
3. Kaushalendrakrdubey,R.S.Mishra "Energy-Exegetic Analysis of combined Reheating – Regenerative Rankine cycle using Entropy Generation of principle" International Journal of recent Technology and Engineering"(2019)
4. Kirankumar Kulkarni, M.R.Nagaraj "Comparative Performance of Reheat and Regenerative Steam cycle by using Program"International Journal for Scientific Research & Development (2016)

5. S. Naga Raju, Dr. N. Hari Babu, P. Dilip Kumar "Analysis of Regenerative System in Steam Power Plant "International Journal of Engineering and Applied Sciences (2015)
6. Raju, S. Naga, N. Hari Babu, and P. Dilip Kumar. "Analysis of Regenerative System in Steam Power Plant." International Journal of Engineering and Applied Sciences 2.7 (2015).
7. Sahu, Gulab Chand, Manoj Sao, and Abhishek Kumar Jain. "Comparison Between Regenerative, Reheat & Cogeneration Steam Plant on the basis of Turbine Inlet Temperature."
8. Habib, M. A., S. A. M. Said, and I. Al-Zaharna. "Thermodynamic optimization of reheat regenerative thermal-power plants." Applied Energy 63.1 (1999): 17-34.
9. Moradimaram, E., and H. Sayehvand. "First and Second Analysis on the Reheat Organic Rankine Cycle." International Journal of Energy and Environmental Engineering 13.6 (2019): 236-242.
10. NagasubbaRayuduPeyyala&Dr.K. Govindarajulu "Thermodynamic Analysis Of 1200 Mw Coal Based Supercritical Thermal Power Plant with Single and Double Reheating" International Journal of Engineering Sciences & Research Technology
11. Mishra, R. S., and Dharmendra Sahu. "Thermodynamic analysis and comparison of various organic fluids for ORC in Gas turbine-Organic Rankine combined cycle plant with solar reheating and regeneration of ORC fluid." International Research Journal of Engineering and Technology (IRJET) e-ISSN (2016): 2395-0056.
12. Kumar, Ch Ashok, S. Udaya Bhaskar, and N. Srinivasa Rajneesh. "Fatigue analysis of four cylinder engine crank shaft." AIP Conference Proceedings. Vol. 2358. No. 1. AIP Publishing LLC, 2021.
13. Rajneesh, N. Srinivasa, et al. "Investigation on mechanical properties of composite for different proportion of natural fibres with epoxy resin." AIP Conference Proceedings. Vol. 2358. No. 1. AIP Publishing LLC, 2021.
14. Pavuluri, Subramanyam, et al. "Effect of reheating cycle on efficiency of Rankine cycle and its practical significance" AIP Conference Proceedings. Vol. 2358. No. 1. AIP Publishing LLC, 2021.
15. S.K. Mohammad Shareef, M Sai Vikas, A.L.N Arun Kumar, Abhishek Dasore, Sanjay Chhalotre, Upendra Rajak, Trikendra Nath Verma, Design and thermal analysis of engine cylinder fin body using various fin profiles, Materials Today: Proceedings, 47(17): 5776-5780 (2021).
16. Surendra, J., Rajyalakshmi, K., Apparao, B. V., Charankumar, G., & Dasore, A. Forecast and trend analysis of gold prices in India using auto regressive integrated moving average model. J. Math. Comput. Sci., 11(2), 1166-1175 (2021).
17. Dasore, A., Rajak, U., Panchal, M. et al. Prediction of Overall Characteristics of a Dual Fuel CI Engine Working on Low-Density Ethanol and Diesel Blends at Varying Compression Ratios. Arab J Sci Eng (2022). https://doi.org/10.1007/s13369-022-06625-8
18. Indrakanth, B., Udaya Bhaskar, S., Ashok Kumar, C., Srinivasa Rajneesh, N. (2022). Design and Optimization of Engine Block Using Gravity Analysis. In: Chaurasiya, P.K., Singh, A., Verma, T.N., Rajak, U. (eds) Technology Innovation in Mechanical Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-16-7909-4_95
19. Subramanyam Pavuluri, Dr.B.Sidda Reddy, Dr.B.Durga Prasad. (2020). An Experimental Investigation on the Performance, Combustion and Emission Characteristics of CI Diesel Engine at Various Compression Ratios with Different Ethanol-Biodiesel Blends. International Journal of Advanced Science and Technology, 29(05), 2215-2226.
20. B. Sidda Reddy, A. Aruna Kumari, J. Suresh Kumar, K. Vijaya Kumar Reddy. Application Of Taguchi and Response Surface Methodology For Biodiesel Production From Alkali Catalysed Transesterification Of Waste Cooking Oil, International Journal of Applied Engineering Research, Vol. 4 (7), pp. 1169–1184, 2009.
21. B. Sidda Reddy, A. V. Hari Babu, S. Sreenivaslulu, K. Vijaya Kumar Reddy, Prediction of C. I. Engine Performance and NOX Emission Using CANFISInternational Journal of Applied Engineering Research, Vol. 5 (5), pp. 763–778, 2010.
22. B. Sidda Reddy, J. Suresh Kumar and K. Vijaya Kumar Reddy, "Response Surface Methodology As A Predictive Tool For C. I Engine Performance and Exhaust Emissions of Methyl Esters of Mahua Oil", Journal on future Engineering & Technology, Vol.4, No.3, PP. 51-58, Februaryt-April2009. https://doi.org/10.26634/jfet.4.3.280