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IMPROVE STEAM TURBINE EFFICIENCY BY USE OF REHEAT RANKINE CYCLE

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ABSTRACT
Steam are a major energy consumer. Optimising process operating conditions can considerably improve turbine water rate, which in turn will significantly reduce energy requirement. Various operating parameters affect condensing and back pressure turbine steam consumption and efficiency.This paper cantaint the effect of opertating condition of turbine back pressure turbine inlet steam tempreture and adavantage of improving inlet steam tempreture by reheat cycle on the efficiency of steam turbine and total energy production of power plant.

KEYWORDS: Turbine efficiency, steam inlet tempreture,dryness fraction.

INTRODUCTION
De Laval, Parsons and Curtis developed the concept for the steam turbine in the 1880s. Modern steam turbines use essentially the same concept but many detailed improvements have been made in the intervening years mainly to improve turbine efficiency.

Energy in the steam after it leaves the boiler is converted into rotational energy as it passes through the turbine. The turbine normally consists of several stages with each stage consisting of a stationary blade (or nozzle) and a rotating blade. Stationary blades convert the potential energy of the steam (temperature and pressure) into kinetic energy (velocity) and direct the flow onto the rotating blades. The rotating blades convert the kinetic energy into forces, caused by pressure drop, which results in the rotation of the turbine shaft. The turbine shaft is connected to a generator, which produces the electrical energy.This energy production can be optimized by using the reheat cycle in steam power plant in which the stem from the boiler should be reheated so the dryness fraction of steam improve by reducing moisture contain in the steam.

EFFECT OF OPERATING CONDITIONS ON STEAM TURBINES
A condensing turbine system is shown in figure 1. Turbine exhaust operating below atmosphere, is condensed in a shell and tube exchanger called surface condenser. Condensate flows in the shell side of the condenser and steam is condensed by the cooling water. Vacuum in the surface condenser i.e. turbine exhaust vacuum is controlled/ maintained by vacuum ejector system of the surface condenser.

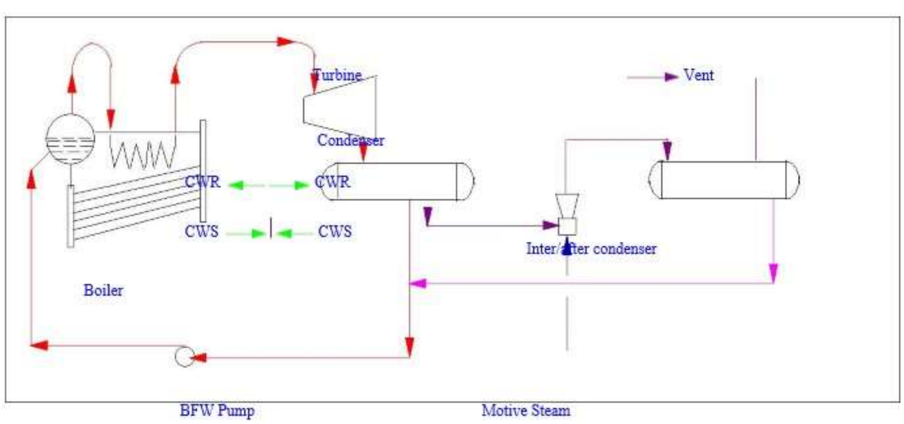

Figure 1: Diagrammatic details of a condensing type turbine

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Turbines are designed for a particular operating conditions like steam inlet pressure, steam inlet temperature and turbine exhaust pressure/ exhaust vacuum, which affects the performance of the turbines in a significant way. Variations in these parameters affects the steam consumption in the turbines and also the turbine efficiency. Theoretical turbine efficiency is calculated as workdone by the turbine to the heat supplied to generate the steam. Efforts are made to show the impact of various operating conditions by considering the following steam conditions as illustration.

Condensing Type turbine		Back pressure type turbine	
Steam inlet pressure	40 kg/cm2a	Steam inlet pressure	40 kg/cm2a
Steam inlet temperature	350 deg C	Steam inlet temperature	350 deg C
Exhaust vacuum	657 mm Hg	Exhaust pressure	4.5 kg/cm2a
Turbine rated BHP	10000 HP	Turbine rated BHP	10000 HP
Steam consumption	27785	Steam consumption	57960

In the above referred turbines, 1 % reduction in steam consumption saves around $ 47000 annually for condensing turbines and around $ 84000 annually in back pressure turbine. LHV of the fuel for generating steam is considered as 10500 kcal/kg and boiler efficiency is taken as 87 %. Effect of various operating parameters is illustrated in the succeeding paragraphs.

Effect of Steam inlet pressure

Steam inlet pressure of the turbine also effects the turbine performance. All the turbines are designed for a specified steam inlet pressure. For obtaining the design efficiency, steam inlet pressure shall be maintained at design level. Lowering the steam inlet pressure will hampers the turbine efficiency and steam consumption in the turbine will increase. Similarly at higher steam inlet pressure energy available to run the turbine will be high, which in turn will reduce the steam consumption in the turbine. Figure - 2a & 2b represents the effects of steam inlet pressure on steam consumption and turbine efficiency respectively, keeping all other factors constant for the condensing type turbine.

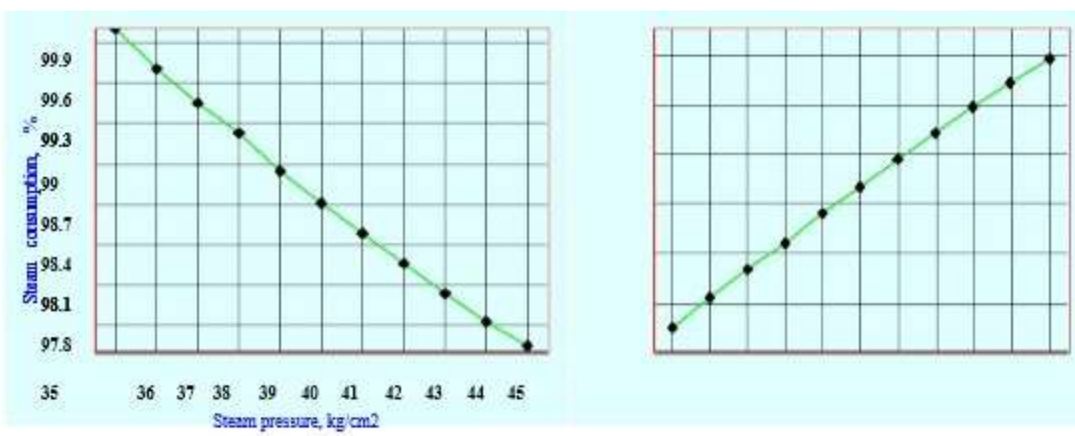

Fig 2a : Effect of steam pressure on steam consumption in condensing type turbine

Fig 2b : Effect of steam pressure on turbine efficiency in condensing type turbine

Figure - 2a & 2b indicates that increase in steam inlet pressure by 1 kg/cm2 in condensing type turbine reduces the steam consumption in the turbine by about 0.3 % and improves the turbine efficiency by about 0.1 % respectively.

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In case of back pressure type turbine increase in steam inlet pressure by 1 kg/cm2 reduces the steam consumption in the turbine by about 0.7 % and improves the turbine efficiency by about 0.16 % as shown in figure - 3a & 3b . Improvement in back pressure type turbine is more than the condensing type turbine.

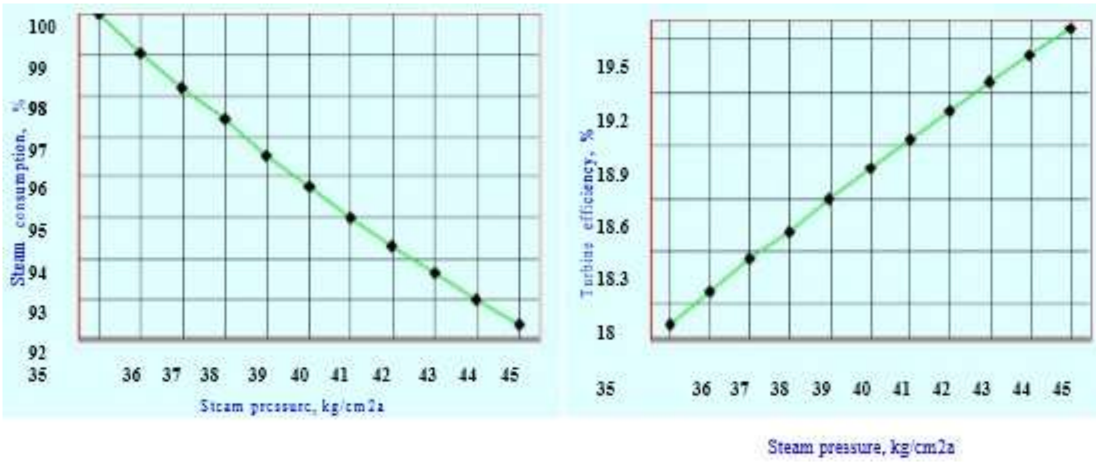

Fig 3a : Effect of steam pressure on steam consumption in back pressure type turbine

Fig 3b : Effect of steam pressure on turbine efficiency in back pressure type turbin

Effect of Steam inlet temperature

Enthalpy of steam is a function of temperature and pressure. At lower temperature, enthalpy will be low, work done by the turbine will be low, turbine efficiency will be low, hence steam consumption for the required output will be higher. In other words, at higher steam inlet temperature, heat extraction by the turbine will be higher and hence for the required output, steam consumption will reduce. Figure - 4a & 4b represents the effects of steam inlet temperature on steam consumption and turbine efficiency respectively, keeping all other factors constant for the condensing type turbine.

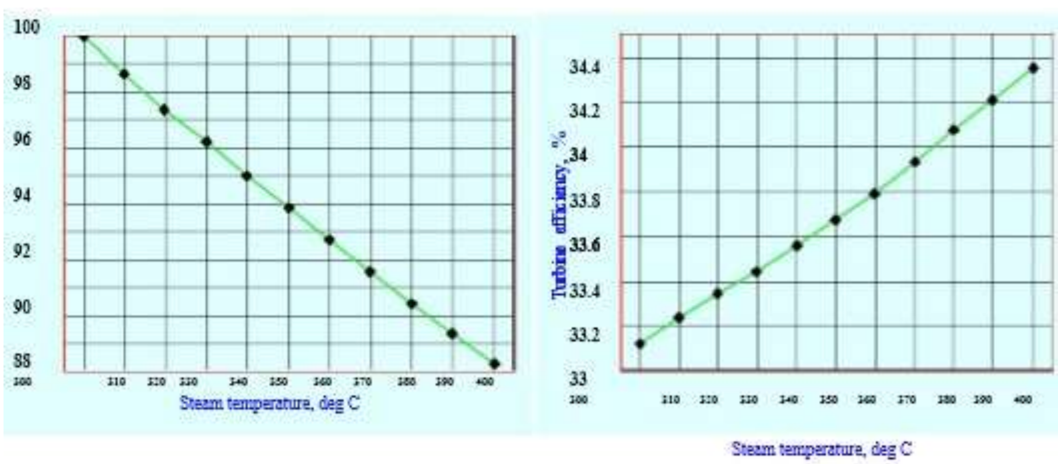

Fig 4a : Effect of steam temperature on steam consumption in condensing type turbine
Fig 4b : Effect of steam temperature on turbine efficiency in condensing type turbine

Figure - 4a & 4b indicates that increase in steam inlet temperature by 10 deg C in condensing type turbine reduces the steam consumption in the turbine by about
1.1 % and improves the turbine efficiency by about 0.12 % respectively.

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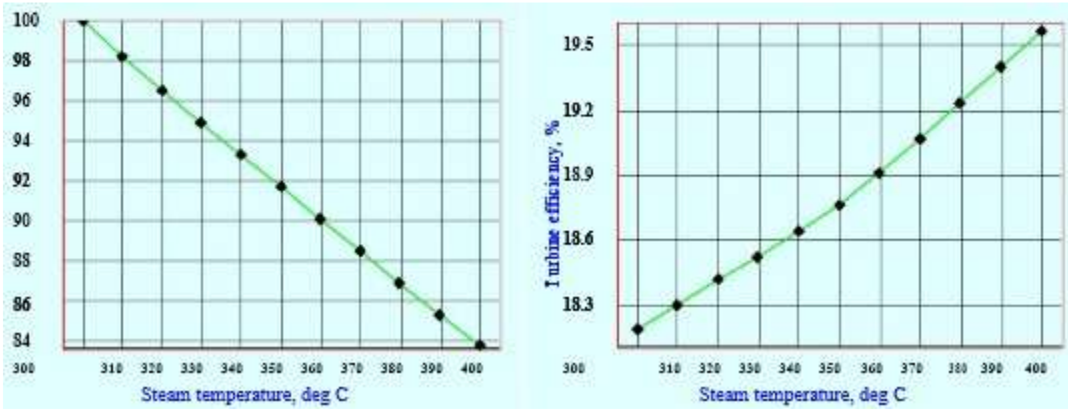
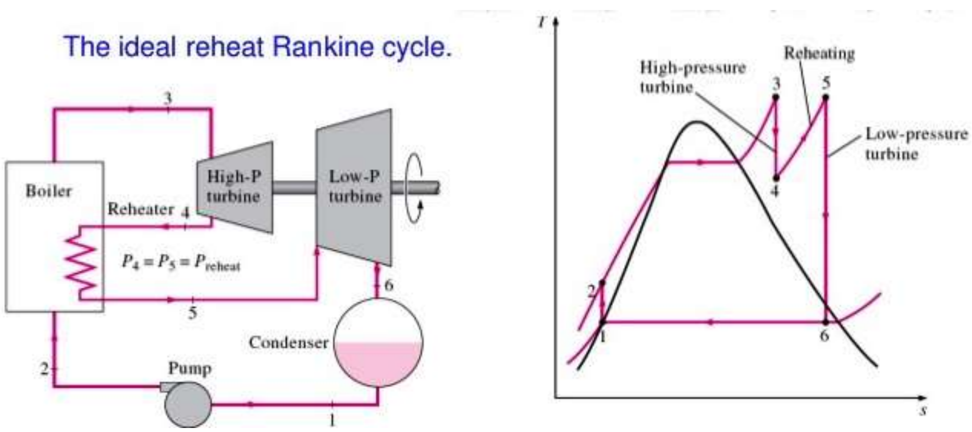


Fig 5a : Effect of steam temperature on steam consumption in back pressure type turbine.
Fig 5b : Effect of steam temperature on turbine efficiency in back pressure type turbine.

In case of back pressure type turbine increase in steam inlet temperature by 10 deg C reduces the steam consumption in the turbine by about 1.5 % and improves the turbine efficiency by about 0.12 % as shown in figure - 6a &6b. Improvement in back pressure type turbine is more than the condensing type turbine.

REHEATING OF STEAM TO IMPROVE THE TURBINE EFFICIENCY



causing a reduction of the internal relative efficiency of the turbine, ; this in turn leads to a reduction of the effec¬tive (thermal) efficiency of the power plant as a whole. For modern turbines the admissible dryness fraction of exhaust steam (at the turbine exit) should be not less than x = 0.86 to 0.88.

As has already been mentioned, one of the ways to reduce the wetness of exhaust steam at the turbine exit is to superheat the steam in the boiler. Superheating leads to an increase in the thermal efficiency of the cycle reali¬zed, and at the same time, on the T-s diagram it shifts the point corresponding to the conditions of exhaust steam to the right, into the region of greater dryness fractions, as illustrated in Fig. 11.20a.

We have also found that with the same superheat temperature the use of high pressures increases the cycle areas ratio and, consequently, the thermal efficiency of the cycle, but simultaneously a higher pressure diminishes the dryness fraction of the exhaust steam and the internal relative efficiency of the turbine.

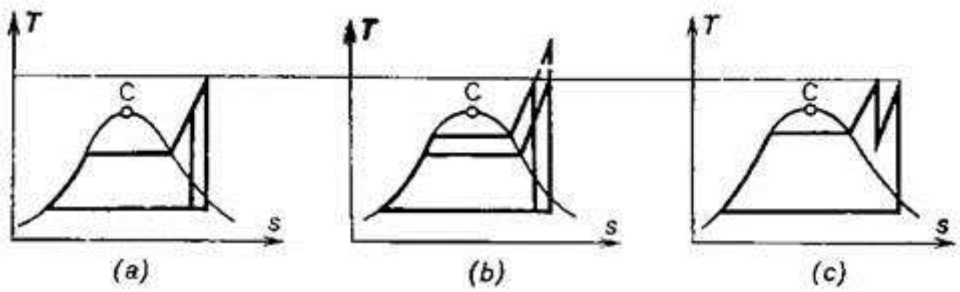


Fig. 11.20

One solution could be to further increase the superheat temperature (the dotted line in Fig. 11.206). However, as was already mentioned, further temperature increases are restricted by the properties of construction materials. The economic advantage of this undertaking should also take into consideration increased investments involved in building such a plant.

One way to reduce the final wetness of exhaust steam is to reheat the steam. After the flow of steam, performing work in the turbine, expands to some pressure p*> p2, it is extracted from the turbine and directed to flow into an additional superheater, or reheater, installed, for instance, in the boiler flue. In this reheater, steam temperature rises to T*, and then the steam flows back into the turbine, in which it expands to the pressure p2. As can be seen from the T-s diagram, shown in Fig. 11.20c, the final wetness of steam diminishes.

The diagram of a power plant with steam reheating is shown in Fig. 11.21, in which the reheat superheater, or reheater, is designated by RS. When reheating the steam, the turbine is a two-cylinder unit, comprising a high-pressure turbine and a low-pressure turbine[1] arranged on a common shaft along with a generator.

Figure 11.22 shows on a T-s diagram an internally reversible reheat cycle of the steam power plant, practising superheating. It is clear that this cycle can be visualized as consisting of two individual cycles, the conventional Rankine cycle (main) 5-4-6-1-2-3-5 and an additional cycle 2-7-8-9-2 (the line 7-8 is an isobar p*= const). It can be assumed that the work done along the section 7-2 of the expansion adiabat in the main cycle is spent to ensure adiabatic compression of the working medium on the section 2-7 of the additional cycle.

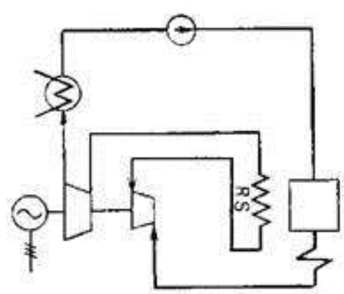


Fig. 11.21

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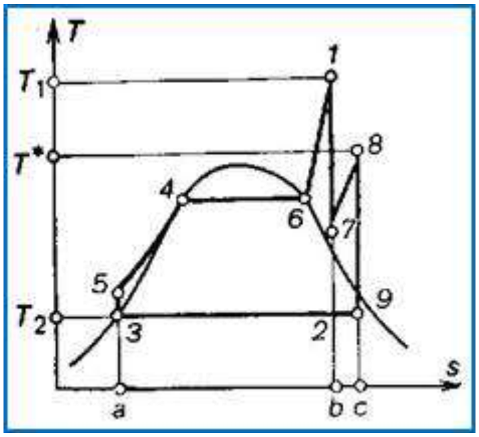

Fig. 11.22

The expression for the thermal efficiency of the reheat cycle can be presented in the following form:

$$\eta^{\text{r.c.}} = \frac{(i_1 - i_7) + (i_8 - i_9) - (i_5 - i_3)}{(i_1 - i_5) + (i_8 - i_7)}. \tag{11.107}$$

If the thermal efficiency of the additional cycle,

$$\eta^{\text{ad}} = \frac{(i_8 - i_9) - (i_7 - i_2)}{i_8 - i_7}, \tag{11.108}$$

is greater than the thermal efficiency of the main cycle,

$$\eta^{\text{main}} = \frac{(i_1 - i_2) - (i_5 - i_3)}{i_1 - i_5},$$

then the thermal efficiency of the reheat cycle, $\eta^{\text{r.c.}}$, will be greater than the thermal efficiency of a Rankine cycle without reheating (i.e. greater than that of the main cycle):

$\eta^{\text{r.c.}} > \eta^{\text{main}}$.

In fact, if $\eta^{\text{ad}} > \eta^{\text{main}}$, it means that the area ratio of the additional cycle is greater than that of the main cycle and, consequently, the area ratio of the total reheat cycle is larger than the area ratio of the main cycle.

Steam reheating, practised at one time mainly to do away with the high wetness of steam in the last stages of turbines, is now used to increase the thermal efficiency cycles.

Analyzing the T-s diagram, we see that if steam is returned for reheating at a temperature not very low and it is being reheated to a temperature close to T1, the thermal efficiency of the additional cycle will be higher than the thermal efficiency of the main cycle; in this case the area ratio of the additional cycle will be far greater than that of the main cycle (Fig. 11.23).

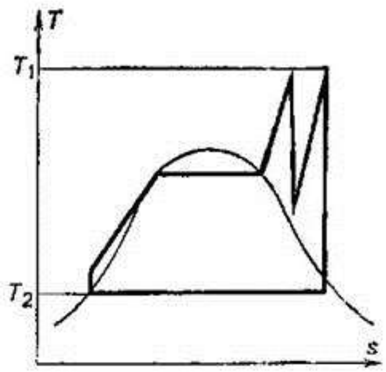

Fig. 11.23

A cycle with steam reheating to a temperature T* = T1 is shown on the i-s diagram in Fig. 11.24.

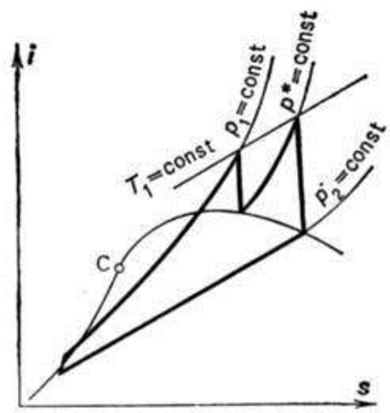

Fig. 11.24

Modern steam power plants are usually operated not only with single but with double steam reheating.

Steam reheating used in steam power plants as a means for raising the thermal efficiency of the plant, is similar to the two-stage heat addition in gas-turbine plants, considered in Sec. 10.2.

Advantage & Disadvantage of reheating of steam

Advantages of Reheat Cycle in Thermal Power Plant

- There is a limit to the degree of super-heat due to the metallurgical conditions, therefore it is not possible to get all super-heat in one stage. The inevitable effect of use of higher pressure in power plants is that, the saturation line is reached which is highly undesirable. There is heavy blade erosion due to the impact of the water particles carried with the steam. Therefore, the reheating is essential in high pressure modern thermal power plants to increase the lifetime of the plant.
- The reheating reduce 4 to 5% fuel consumption with a corresponding reduction in the fuel handling
- The reheat cycle reduces the steam flow of 15 to 20% with corresponding reduction in the boiler, turbine and feed handling equipment capacities. This also reduces the pumping power in that proportion.
- The wetness of the exhaust steam with the reheat cycle is reduced to 50% of the Rankine cycle with a corresponding reduction in the exhaust blade erosion.
- Lower steam pressures and temperatures and less costly materials can be used to obtain the required thermal performance
- A reduction in the steam volume and heat to the condenser is reduced by 7 to 8%. Therefore the condenser size and cooling water requirement are also reduced by the same proportion

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- The size of the Low pressure (LP) turbine blades is reduced because specific volume is reduced by 7 to 8%

The advantage claimed by the reheat cycle are higher thermal efficiency, reduced feed water pump power, smaller condenser, smaller boiler, long life of the turbine and less handling of the fuel and firing requirement.
Disadvantages of Reheat Cycle in Thermal Power Plant

- The cost of the extra pipes, equipment and controls make the cycle more expensive than the normal Rankine cycle.
- The greater floor space is reduced to accommodate the longer turbine and reheat piping
- The complexity of the operation and control increases with the adoption of the reheat cycle in thermal power plant.
- All the lighter loads, the steam passing through the last blade rows to the condenser are seriously super-heated if the same reheat is maintained. Feed water is sometimes sprayed into the low pressure cylinders as low steam flows as a precaution against over-heating of blades.

CONCLUSION

Steam Turbines are one of the main energy consuming equipments, eventhough not much attention is paid to them. Trimming of operating parameters are essential for efficient operation of these turbines. Illustration given in the paper shows impact of operating conditions on steam turbines. Savings presented are for a typical operating conditions. Huge benefits can be reaped by optimizing operating parameters, by minor modifications and even by replacing old in-efficient turbines.

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