Performance Enhancement of Steam Turbine, Deteriorated by Scaling Phenomenon: A Review

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ABSTRACT

This Review paper comprises the reasons for the deterioration of the turbine efficiency. In addition to that, it depicts the major and affable researched covered for the particular problem occurred in the decay of the efficiency of the steam turbine. However, the major concern of this review paper is not to focus on the basics of turbine and its working principle. Despite the fact that the contamination of different composition in the steam, evaporating from the boiler, is found adamant to eliminate it totally by mechanical baffles. However, this review paper will discuss, rationally, different ways to reduce the maximum possible contamination of silicon oxide in the steam leaving the boiler, which are found in the deposits on the turbine blade. This paper also describes the mechanism of the nucleation of the deposits on the turbine blade, Relation between boiler water pH and the contamination of silica in the steam, and Effect of Epsom salt, potassium phosphate and sodium phosphate to reduce reduction ratio. It also discusses the current methods to remove the deposits as a part of maintenance program.

Keywords
steam turbine; scaling of turbine blade; Epsom salt; potassium phosphate; sodium phosphate.

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Introduction

Steam Turbines extract energy from steam by a series of expansions through stages, where the expansion is through fixed blading ports, increasing the velocity, and the rotor blades use the velocity to turn the fixed blade expansion is at near constant entropy. But when the impediment takes place in the flow, either the velocity increases or the back pressure generates. The usual consequence of scaling is that power output decreases. This is because the inlet pressure is generally fixed as is the steam flow, hence MW, are set by the choking flow conditions through the nozzles. The effects of scaling more typically take months to years for the reduced generation to be noticeable.

Industry perceptions are that scale has to be significant (greater than 3mm thick) before it affects output. When turbines are dismantled, the scale is often thicker than this, and in some cases, partially blocking the nozzles of the stationary blades of the turbine. However, the techniques to reduce the silica proportion in the steam before entering the boiler water surface will be considered as a propitious solution.

Major Factor Affecting Efficiency

As the overall efficiency of the thermal power plant also depends on the efficiency of the steam turbine. It is very essential to consider the factors affecting the efficiency of steam turbine that has asserted a great chasm between theoretical efficiency, according to optimal parameters, and operational efficiency. The research in major issues, in different areas, carried away by eminent people, Mr. Oataker Jonas and Mr. Lee Machemer (Steam turbine erosion and scaling), has been briefly described here.[1]

1. Vibrations in steam turbine
2. Scaling in steam turbine
3. Balancing in steam turbine.
4. Corrosion and Erosion in turbine blade and Casing

So, it is very necessary to identity the problems occurring during operation of steam turbine and what are the current research programmes, have been done on the different phenomenon that affects the turbine efficiency directly or indirectly. The above listed problems have different contribution in the deterioration of the efficiency. Silica deposits found in the turbines are undoubtedly the result of the vaporization of silicic acid from the boiler water. Once the silicic acid is present in the steam as a vapor, it becomes rather difficult to remove it; consequently, the major amount of effort should be expended in the direction of removal of silica from the boiler water. However, in many instances this removal may be very difficult to effect, and in these cases, it may be possible to reduce the silica content of the steam by various means.

From the figure 1 it can be concluded that Mechanical vibrations and Stresses due to vibrations have the most deteriorating influence on the efficiency of steam turbine which is followed by the Scaling phenomenon and Thermodynamic design and Non-optimum conditions acquires 20 % of the graph. Following to that, the minimum influence in deteriorating the turbine overall efficiency is incorporated by the poor manufacturing and maintenance which comprises the cleaning and polishing of turbine blades, taking care of rubbing of blades and so on. As the vibration is concluded the major peril for the turbine efficiency, there has been done a lot of research in this field.

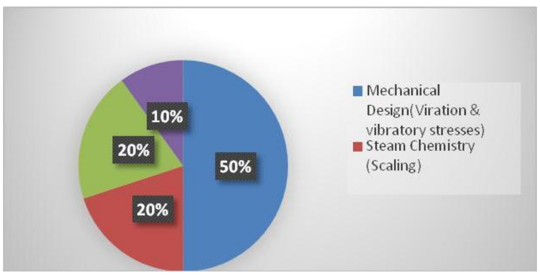

Fig 1. Percentage affecting efficiency of turbine

But as the scaling phenomenon is very capricious and insidious, also the causes of the unbalance forces acting on the turbine shaft which will result in radial vibration, so scaling would be hot topic to dig up at a bachelor level. Furthermore, Vibration due to unbalance mass has been taken care in the maintenance operations.

CAUSES OF STEAM CONTAMINATION

It is very important to know the sources of the compositions of the deposits found on the turbine blade. As Mr. K.S. Venkateshwarlu has done phenomenal work and cited the main three reasons for the contamination in the steam in his book, Water Chemistry for industrial and power station water treatment. [2]

i) Mechanical entrainment of boiler water:

When the boiler water is mechanically entrained in the steam, it is possible to reduce this material to a very small value by means of mechanical steam purifiers.

ii) Solubility of salts in steam:

At lower pressures, steam has not been found to have the property of dissolving the salts found ordinarily in boiler water. Under this condition, the use of mechanical purifiers, which merely separate the boiler water from the steam, would have no effect in removing the salt actually dissolved in the steam.

iii) Vaporization of salts in steam:

At higher steam pressures, it is possible that materials present in the boiler water might have a vapor pressure of a magnitude sufficient to have appreciable amounts of the material present in the steam as a vapor. Mechanical purification would not separate the vaporized material from the steam.

Mechanism Of Scale Formation

The deposition of the scale at the surface of the turbine blade is occurred by the nucleation process. Nucleation process is very convoluted and capricious. But the nucleation process largely depends on the temperature, pressure, nature and the size of the solid particle and nucleation sites. Nucleation takes place as either homogeneous nucleation or heterogeneous nucleation. As cited in the „Mechanism Of water droplets deposition on turbine blade surface and erosion wear effect by

G.lieva (Centre of Mechanical and aerospace science and technology, Portugal), Nucleation takes place as either homogeneous nucleation or heterogeneous nucleation. Nucleation without preferential nucleation sites is called homogeneous nucleation. However, the heterogeneous starts with the preformed surface in this type of nucleation. [4]

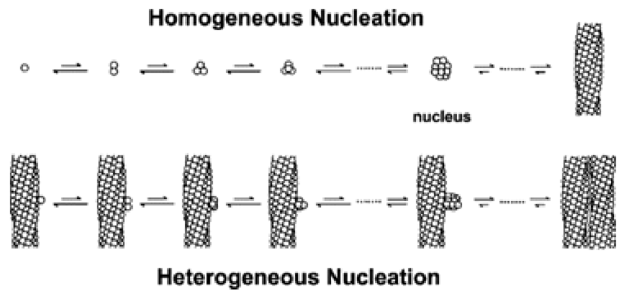

Fig 2. Mechanisms of Water Droplets Deposition on Turbine Blade Surfaces and Erosion Wear [1]

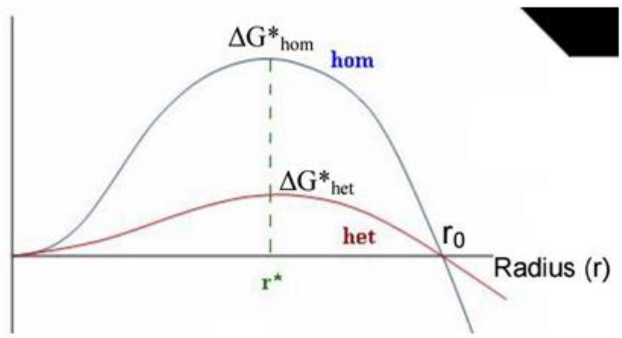

Fig 3. Gibb‟s free energy v/s Radius of group atoms [6]

As shown in the figure 3, as the radius of the nucleus cluster increases, up to critical radius(r*), the required Gibb‟s free energy for the bond increases. For the radius greater than the critical radius, the Gibb‟s free energy decreases with the increase in the radius. The monomerization and polymerization of the silica have analogy with the concept of Gibb‟s free energy depicted by the [6] Xiaodu Xu(Silica Scaling in water treatment : mechanism and mitigation)

A. Repercussions of Scale Deposits

- Distortion in the original shape of the nozzle and the turbine blade
- Increased resistance to the flow of steam.
- Due to that it creates back pressure in the turbine
- Reduced capacity and efficiency of the turbine.
- Cause excessive rotor thrust.
- Can unbalance the turbine rotor, causing vibration problems.
- Stress Corrosion Cracking can occur.

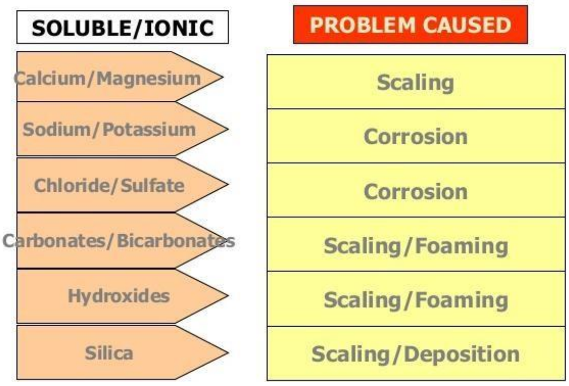

Fig 4. Chemical composition in steam and its consequence [6]

B. Factors affecting Scale Formation

- Nucleation
- Contact time
- PH/ Alkalinity
- Pressure
- Flow velocity
- Presence of impurities

From the given parameters, only pH and the impurities are the controlled ones. As nucleation phenomenon is very capricious and unpredictable. In addition to that contact time is contingent to the flow velocity and surface area of the blade. Pressure and velocity of steam are design parameters which are based on the output of the turbine.

It very essential to know the composition of the deposits found in the last stage of steam turbine to establish the remedy and to abrogate the phenomenon of scaling in the most effective way. At the Siemens facility, by the use of PMI gun, which works on the x-ray principle, we are able to portray that silica is the biggest malign in the scaling.

Table 1. Composition (%W/W) in scale deposits in the last stage of steam turbine

Chemical Components	Reading No. 1 (% by weight)	Reading No. 2 (% by weight)
Silicon (Si)	87.2	80.5
Iron (Fe)	1.47	1.35
Copper (Cu)	2.36	0
Calcium (Ca)	0	0.01
Magnesium (Mg)	0	0
Aluminium (Al)	1.54	0.6
Sodium (Na)	0	0
Phosphorous (P)	0.21	0.18

From the both data, it can be shown that from 80-87 % of the total weight of the deposits is of silica. So, the pinnacle has been reached by the different chemical components of silica in the given weight of the deposit. The copper and ferrous and ferric ions are also found in the data, which will commensurate the reasons for the corrosion. Sodium hasn"t detected so far. The Calcium and magnesium composition can be reduced by the lime Softening treatment. The Aluminum and Phosphorous composition is present as infinitesimal portion of total weight of the scale deposit.

Silica exists in various forms. The soluble form of silica is initially monomeric, as it contains only one silicon atom. In this form it is often called Monosilicic acid. Monosilicic acid is generally deionized at most natural pH levels.

As Mr. Ibrahim S. Al-Mutaz and Mr. Ibrahim Ali Al-Anezi cited that at a pH of 8.5 only 10% of the Monosilicic acid is ionized and, as the pH reaches 10, 50% is ionized. Polymerization of mono-silicic acid is initiated in the presence of hydroxyl groups when only fractional ionization exists. It is also espoused by the Mr. Venkateshverlu in his book of water chemistry. [2] [7]

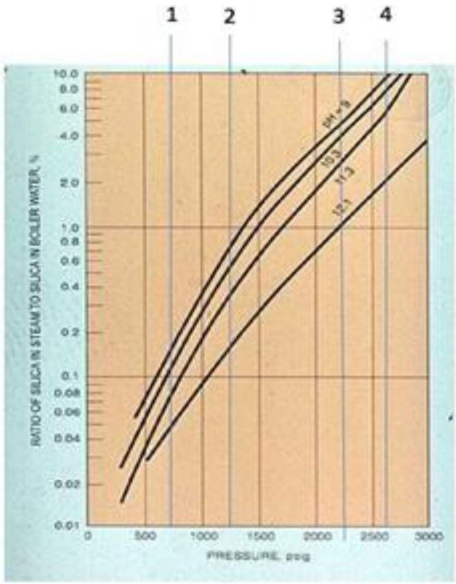

Fig 4 pH v/s Silica [7]

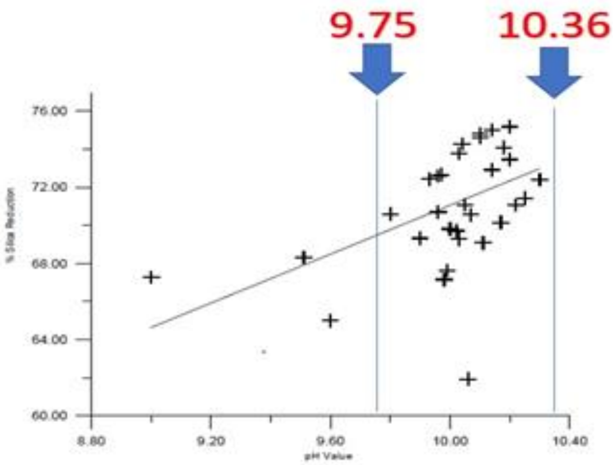

Fig 5 % Silica Reduction v/s pH Value [2,7]

From the above figure 5, it is concluded that the working pH range is between 9.75 to 10.36. The increased in pH gives less reduction ratio that will be discussed in the next section.

Silica reduction by adding Epsom Salt

The action of the magnesium appeared to be that of adsorption instead of precipitation as definite magnesium silicate while the presence of NaCl or KCl does not retard this action. Silicon dioxide in the water reacts with the magnesium ion of the Epsom salt which results in the solid magnesium silicate.

Chemical reaction between Magnesium of Epsom salt and silica:

Silica reduction by adding Potassium Phosphate
The potassium phosphate has the same effect in reducing the reduction ratio. The chemical process takes place is described below:

$$SiO_2 + 4Mg \rightarrow 2MgO + Mg_2Si$$

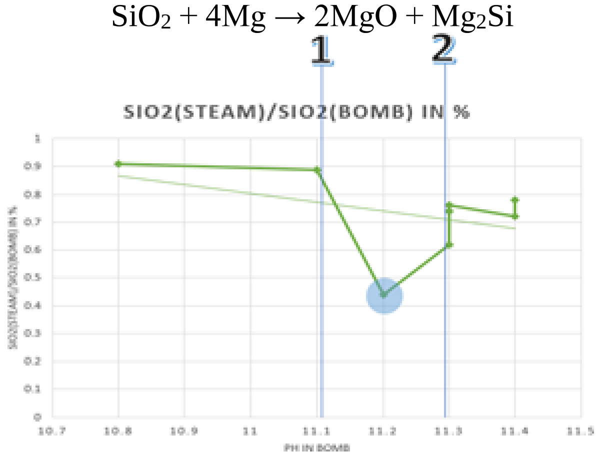

Fig 6 Addition of 0.05-gram Epsom Salt in the Bomb[7]

From the previous section we can delude that to impede the polymerization of the silica it is expedite to increase the pH of the Boiler water. In the Figure 7, 0.1-gram Epsom salt is added in the 750 ml of water. The experimental data depicts that the reduction ratio, which is defined as the silica in steam to the silica in the boiler water, vacillates between 0.7, at upper limit, and 0.45, at bottom line which portrays that the only 0.45% of the total silica has leaved the surface of the boiler water. From the Figure 6, it is deluded that higher value of the pH of the boiler water has commensurate the lower proportion, of .05-gram, of the Epsom salt.

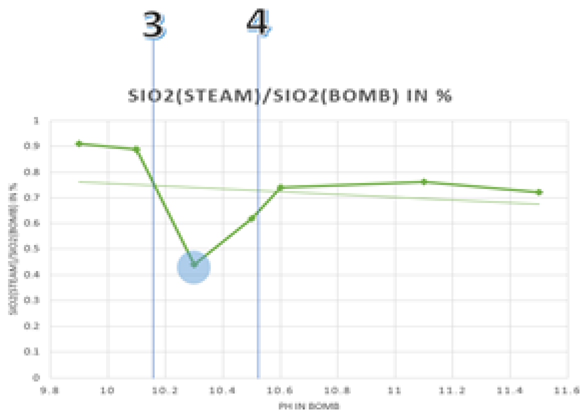

Fig 7 Addition of 0.1-gram Epsom Salt in the Bomb

$K3PO4 + 2SiO_2 \quad K_2SiO_3 + K_2Si_4O_5 + 2H_2O$

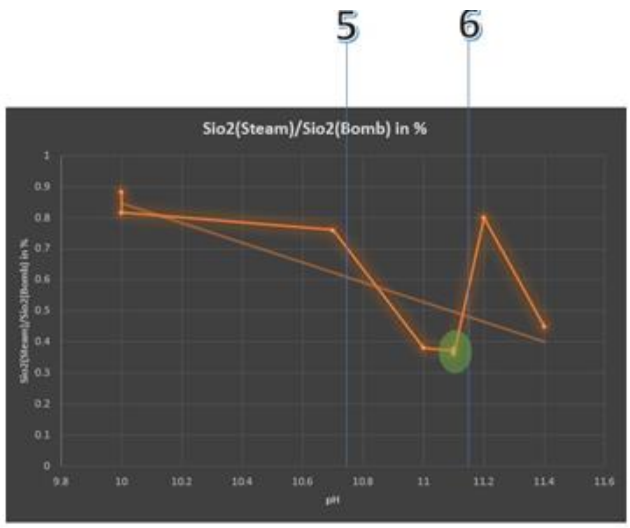

Fig 8 Addition of 0.02-gram potassium phosphate

The experimental data depicts that in the alkaline medium the reduction ratio has been decreased further compare to Epsom salt. In this case the reduction ratio is about 0.38% at the pH value of 11.4, approximately.

Silica reduction by adding Sodium Phosphate

Sufficient sodium hydroxide (NaOH) was added to keep the boiler water alkaline. But in this case, the more sodium content will precipitate as solid Sodium silicate on the surface of the boiler.
The chemical reaction is given below.

$$2x\, Na_2SO_4 + C + 2\, SiO_2 \rightarrow 2\, (Na_2O)_x{\cdot}SiO_2 + 2\, SO_2 + CO_2$$

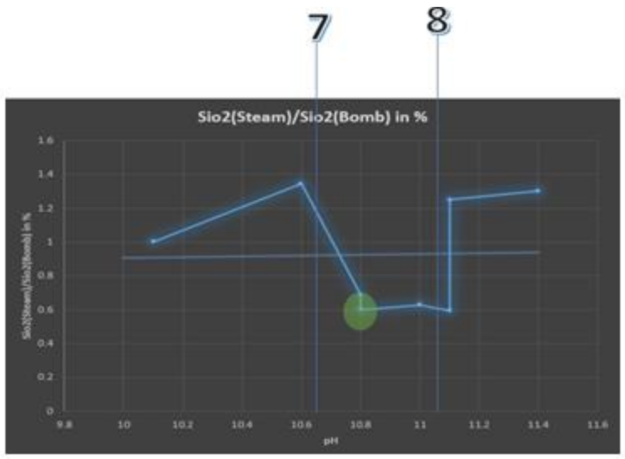

Figure 9 Addition of 0.02-gram Sodium phosphate

Result And Discussion

The comparison table is shown below where the results from different research have compared and cost analysis had been done.

Chemical Compositi -on	Worki- ng pH Range	Reducti on Ratio (Max.) In %	Reducti on Ratio (Min.) In %	Addit ion of chemi cal comp ositio n(gm)	Total Cost /day (Rs.)
Epsom Salt	11.0-11.32	0.90	0.45	0.05	9000/-
Epsom salt	10.16-10.6	0.90	0.45	0.10	17,920/-
Potassium Phosphate	10.7-11.2	0.75	0.38	0.02	1700/-
Sodium Phosphate	10.6-11.15	1.21	0.60	0.02	13,440/-

Conclusion

The increase in alkaline medium begets the reduction in polymerization of the silica and it remains in the monomer form. In the pH range of 9.75 to 10.36, the possible reduction in the silica, leaving the boiler water surface, is approximately 68% to 75%. However, to allow infinitesimal silica in the steam total amount of silica or to achieve the minimum reduction ratio, it is propitious to add the expedite amount of Epsom salt/ Potassium Phosphate/ Sodium Phosphate. The pH range is covered from the 10.16 to 11.32. The most economical way to reduce the silica content is to add Potassium Phosphate as its price is relatively low and reduction ratio is minimum. However, the result of the chemical reaction engenders the solid sludge which will precipitate at the bottom surface of the boiler and affects the heat transfer rate.

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