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Role of Corrosion Inhibitors and Mixed Inhibitor Effect in Cooling Tower Chemical Treatment

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Abstract

Selection of a suitable additive is one of the energy saving measures. For energy saving in cooling tower it is essential to select proper treatment. The paper represents the mechanism, control measure & practice for efficient cooling water treatment. Depending of type of condenser tube material, water quality antiscalant, biocides and inhibitor are selected This paper also represent on future scopes and alternative measures reference to open systems.

Keywords: Water treatment,cooling tower,corrosion,biocides

Introduction

The main aim of cooling water treatment to prevent scale, corrosion & fouling . The metallurgy of the condenser, the working conditions, and the water used would all benefit from a proper water treatment. In addition, the treatment program must be implemented and tracked continuously. Corrosion and other similar issues cannot be completely avoided, but they can be successfully minimized by proper treatment and material selection

SELECTION OF TREATMENT PROGRAM

A good water treatment system should be chosen based on useful inputs from different sources, such as laboratory treatment screening. chemicals, pilot plant experiments, short-term field tests, and related plant histories are all sources of information. Following the selection of the required treatment protocols, the next step is to ensure adequate chemical application and prompt response to unexpected incidents. It is important to verify the additive concentrations and the optimal values needed for desired outcomes on a regular basis. For a quick evaluation of additive concentration, advanced techniques should be used. For example chemiluminescence of the circulated water can be compared to that of water in storage to determine the concentration,in order to make speedy and accurate measurements and facilitate maintenance. Controlling the amount of treatment chemicals can also be done by taking direct samples of one or more chemically active polymers. Polymers that are often used as scale inhibitors and dispersants can occur in both free and bound states in aqueous system.The total polymer level can be used to calculate the amount of treatment chemicals to apply to the system, while the free polymer to total polymer ratio can be used to calculate the dose needed to keep the system running. A side stream taken from the recirculating stream and passed through another cell is successful in removing solid suspensions and checking optimum values, particularly in removing solid suspensions.. A test cooler as well as continuous corrosion testing may be used to determine the effectiveness of cooling water treatment. Depending on the consistency of make-up water and the amount of concentration periods, the blow down should be performed regularly or constantly.

Additives and CorrosionInhibitors

Corrosion is one of the four major problems that exist in cooling water systems; the other three are:

1. **Mineral scale formation,**
2. **Solid deposition**
3. **Microbiological fouling.**

These processes are interrelated and occur simultaneously. Corroding steel surfaces are prone to mineral scale formation, and the deposits can lead to localized under deposit corrosion. Microbiological slimes provide the glue that helps bind deposits to metal surfaces and can also lead to microbiologically induced corrosion. Corrosion on metal surfaces can be prevented by the use of corrosion inhibitors. Oxidizing and non-oxidizing biocides can control microbiological slime. Scaling and TDS can be minimized by the application of ant scaling agents and by the use of polymeric dispersants.

Selection of a suitable inhibitor is one of the energy saving as well as a material saving measures in a chemical industry especially in the cooling water systems. They protect both, ferrous and non-ferrous metals in diverse corrosive environments like cooling waters, paint pigments, conversion coatings, engine coolants, hydraulic and metal working fluids, brines, acid media, lubricants, boiler waters. They protect concrete steel reinforcing bars, batteries, aluminum beverage cans, brake linings, metallic glasses, etc. Hundreds of chemicals - both inorganic and organic have been reported and recommended as inhibitors of corrosion, for various metals in various environments, but to choose the suitable one in optimum concentration is the essential technique.

Considerations for effective inhibition

For an inhibitor treatment to be effective, it should meet some important criteria. The following are some important condition of selection of inhibitor which should be kept in mind for effective cooling water treatment

i) The whole condenser system must be protect from corrosion
ii) Inhibitor concentrations at low levels must be successful.
iii) The chemical treatment must be successful under a large range of conditions such as temperature ,pH,heat flux, flow conditions and water quality

Environmentally permissible discharge toxicity threshold discharge.There should be no deposits on the metal surface that obstruct heat transfer. Inhibits the formation of carbonate and sulfate scales. Microorganism-caused biological activity should be combated.The inhibitor should be appealing in terms of price as well

Inhibition in aqueous systems

The most popular corrosion-inducing conditions to which corrosion inhibitors are added are aqueous ecosystems. The degradation of metals in near-neutral solutions results in the formation of sparingly soluble surface materials such as oxides, hydroxides, and salts. The inhibitor prevents the oxide surface or other layers of the surface from harmful anions. Corrosion is more serious in open systems, so strong inhibition is important. The corrosive aspect of the cooling water is mostly due to oxygen concentration and dissolved solids precipitation due to constant evaporation (chief result of cooling). The cooling tower easily picks up airborne solids such as SO2, NH3, and H2O Since metals adsorb ions from dissolved salts in water, inhibitors have a tougher time getting to the metal surface and displacing the adsorbed ions. In cooling waters, low to moderate salt concentrations are often used.

Factors affecting corrosion inhibition

In the evaluation of corrosion inhibitors for open cooling water systems, the following factors must beconsidered.

i) Both before and after contamination, the chemical makeup of the recirculating water.
ii) The maximum and minimum operating temperatures.
ii) Operating temperature limits.
iii) The pH scale and its variations.
iv) Suspended subject is present.
v) Biological constituents are present.
vi) Heat transfer surfaces' effect on the circulating fluid and vice versa
vi) The inhibitor dosage needed to maintain a specified degree of regulation..
vii) The components used in the system's construction.
vii) The effects of heat exchanger and piping system architecture.
viii) The impact of different fluid rate.
ix) Pollution as a result of a spill.
x) Saturation of oxygen in cooling towers, as well as the breakdown of water-soluble gaseous compounds like SO2.
xi) xii) The tower's physical location and surroundings.

Considering all of these conditions in a test loop is obviously impractical. In general, the most critical variables are studied, such as water chemical composition, circulation and flow rate, aeration, temperature, pH, and so on, while other parameters are ignored or held constant.

BIOCIDE

Without successful microorganism control-, cooling tower structures easily become septic and biofouling causes severe losses. Aerobic slime-forming microbes, algae, fungi, and, in certain cases, protozoa and pathogenic bacteria colonize unregulated cooling systems.Anaerobic bacteria, such as sulphate-reducing bacteria, cause a lot of corrosion. Bacteria produce organic acids, resulting in a slightly acidic pH in the biofilm system. Apart from inducing corrosion, bacterial slimes will significantly increase the energy demand of the system.Anaerobic bacteria, such as sulphate-reducing bacteria, cause a lot of corrosion. Bacteria produce organic acids, resulting in a slightly acidic pH in the biofilm system. Apart from inducing corrosion, bacterial slimes will significantly increase the energy demand of the system.

The choice of biocides depend upon the make up water,cooling water supply, conditions of system and site.Most of industries are adding inhibitor & biocides at same point in cooling water system. However many research were carried out and later it found inhibitor should be added after killing microorganisms

The local environment at the metal/biofilm interface undergoes dramatic changes in terms of pH, dissolved oxygen content, and ionic species concentration once a biofilm forms.

The most challenging aspect of dealing with biofilms is their resistance to chemical treatment.

Biofilms in cooling waters were studied electrochemically. They demonstrate that the metabolic processes of the complex consortia of algae and bacteria in the natural biofilm can cause crevice corrosion. This happens even in low-chloride zones.

Effective microbiological control necessitates continuous monitoring of microbial levels as well as real microbiocide treatment levels. Systems that are clogged should be cleaned and should be treated with acid and biocides on a daily basis .Installing covers to keep the sun out would help.

Biological growth, such as algae, is considerably reduced. It is preferable to use continuous or shock chlorination. The majority of bacteria are destroyed. If there is a lot of rain, Alkaline Issues, as well as microbiological issues Treatment with a non-oxidizing microbiocide is also recommended.

obligatory Non-oxidizing micro biocides are poisonous. However, it is biodegradable. The number of times you add anything will vary. Depending on bacterial development, a decision will be made. Ammonium compounds biocides can be selected . Solid metal catalysts in the form of wire mesh materials, which are placed in plastic racks Significant disinfection is possible. he catalyst has a concentration of 5 mg/kg and is used in the 1 mg/kg for the surviving cooling circuit Because suspended matter causes an unfavorable H2O2 composition .Solid metal catalysts in the form of wire mesh materials, which are placed in plastic racks Substantial disinfection is possible. If the peroxide is present, the result is secured. prior to concentration in the water .The catalyst has a concentration of 5 mg/kg and is used in the 1 mg/kg for the surviving cooling circuit Since suspended matter causes an unfavorable H2O2 composition It is possible to use partial flow filtration applied to get rid of it Nonetheless, the corrosion inhibitor compatibility

Anti-scaling agents and dispersants

Scale is formed when calcium and magnesium salts combine to form deposits. It can be avoided by decreasing the pH of the cooling water and/or using scale inhibitors such as sodium hexa meta phosphate, phosponates, polymeric dispersants, or a combination of the two. Mineral scale formation and dispersed system deposits can be controlled with scale control polymers. Biodegradable polymers are still being developed, with the goal of improving efficiency and cost effectiveness over conventional low molecular weight dispersant polymers. Acrylic acid, methacrylic acid, maleic acid, or other co-monomers with various functional groups have been found to be the most effective .A polymer's able to function as a dispersant, metal ion stabilizer, and/or a solvent Whether to use a precipitation inhibitor or not is entirely dependent on the situation. Ionic composition, molecular weight, and polymer composition a charge As dispersants, organic polymers are used. polymers that ionize to form anionic anionic polymers become charged adversely polymer species that are negatively charged The charge density is absorbed by the a coolant surface that imparts the same charge particles are still present. Suspended due to a charge repellent. The molecular weight of the polymer is kept less than 1000 .Reduced scale deposition can be achieved by using appropriate templates and applying special treatments.In the case of cooling, for example, magnetic technique is used.The scale-prevention mechanism is water circulation.Micro crystals have been observed to form as a result of this discovery.in the water In certain instances, scaling agents must be removed.It will be implemented using specialized techniques. For this reason,For starters, a pair of electrodes with or without ionization.It's possible to use a swap membrane to extract or replace something

Alternative selection

Alternative water treatment methods such as ozonation or ionisation are also used to reduce water and chemical consumption.Ozone can also be used for bacterial disinfection, viral inactivation, color, odor, and taste elimination, as well as the removal of algae and suspended particles, among other things. It allows dissolved organic compounds in water to undergo chemical transformations, which may result in microbial regrowth in the water delivery system.Ammonia should also be absent, as regrowth of nitrobacteria will occur if ozonation is used as the final stage. Using high-quality water can aid to a significant degree to stop disasters.Water with a reductive heat exchanger or Water that has been hydrogenated and is super pure can be used. Costs can be greatly lowered. Likewise, the use of water, solution, or by using a built-in industrial unit, gas can be generated. investigated One of the most powerful the author's alternate approaches option, which has the potential to grow in the future The formation of future growth as well as the use of stray current for metal security through cathodic protection and structures consisting of alloys without running and low maintenance cost

Techniques and mechanisms for R&D are currently in progress.

An amalgamation of electrochemical research and Surface analysis methods of the present day are important for elucidating the corrosion inhibition process procedures Among the surface inspection techniques are AES, XPS, SEM, ESCA, IR, SIMS, among other techniques.Raman and surface improved argon ion sputtering Raman spectroscopy, for example. Electrochemical methods are one example.

For studying growth, a quartz microbalance can be used.Anodic oxide film kinetics, partial oxidation, and The action of passive iron in terms of dissolution and the chemical inhibitors adsorption on iron

Phosphonates are an interesting inhibitor.

Corrosion, scaling, and fouling can all be prevented with phosphonate-based cooling water treatment.

Organophosphonates are more hydrolytically stable. They're also stable over a broad pH spectrum. Temperatures of activity Phosphonates are beneficial. Chelating officers and deposit management agents Organo (organic) Phosphates are non-oxidizing and compliant with chlorine.

Dispersive agents and biocides It is, though, When it comes to copper and its alloys, it responds violently.

present on its own In most cases, zinc is applied to suppress the growth of bacteria.

Copper dissolves and forms a stable chelate. for the use of phosphonates Phosphate salts are commonly used.Polymeric phosphonic acids are among the phosphonic acids.Acids are simple to make in a laboratory environment. Alkyl phosphonic acid is one of the most common phosphonic acid compounds.

aryl phosphonic acids, hydroxy substituted alkyl phosphonic acids, and aryl phosphonic acids

N-substituted 1-amino aryl phosphonic acids, and aryl phosphonic acids

phosphonic acids, cyclic phosphonic acids, and polyphosphonic acids are all forms of phosphonic acids.

phosphonic acids, phosphonated polyamides, and other phosphonic acids and phosphonated polyamides

phosphonic acids and Polymers containing molybdate, such as 1,2-bis (triethoxy silyl) ethane, are used to create effective barrier films on iron surfaces. , they have outstanding self-healing powers.

One of the most powerful polymer-based systems polyamides, etc. is polymer systems with carboxyl groups.

Table 1,Specific Condition for selection of corrosion Inhibitor

Corrosion Inhibitor	**pH range**	**Copper**	**Aluminum**	**Steel**
Cathodic Inhibitor				
Molybdate	7.5-10.0	Fair	Fair	Good
Polysilicate	7.5-10.0	Excellent	Excellent	Excellent
Polyphosphate	6.5-8.5	Attacks	Attacks	Excellent
Anodic Inhibitor				
Orthosilicate	7.5-10.0	Good	Good	Good
Orthophosphate	6.5-8.5	Attacks	Attacks	Good

Table 2:Guide lines for Passivation Film Formation and Subsequent Maintenance.

Corrosion Inhibitor	**Initial Dosage(ppm)**	**Maintain Dosage(ppm)**	**Film Formation (Days)**
Cathodic Inhibitor			
Polysilicate	40-60 as SiO2	10-20 as SiO2	‘5-6
Zinc salts	10-20 as zn	3-5 as zn	‘5-6
Polyphosphate	40-60 as PO4	10-20 as Po4	10-12
Molybdate	40-60 as Mo	5-20 as Mo	10-12
Anodic Inhibitor			
Orthosilicate	40-60 as SiO2	10-15 as SiO2	5-6
Ortho phosohate	40-60 as Po4	15-20 as Po4	10-12
Copper Corrosion inhibitor			
Tolyltrizole	10-20 as TTA	1-2 as TTA	5-6

2. Experimental Procedure

A hot plate and stirrer were used for experimental analysis.A 500 ml beaker is filled with corrosion inhibitors and sample plate immersed for 1 to 5 days.The plate is made up of carbon steel as shown in below Table.The Plate with size(11x4x0.3)cm and with (10x3x0.35)cm rectangular made up of carbon steel were cleaned by abraded by using emery paper of various grade numbers like 220,320,600 and cleaning is done by using distilled water.Then further it is cleaned with acetone and allow to dried for 30 minutes.

Different concentration of corrosion inhibitor were prepared, (20, 40, 60 and 80 ppm) mixt$_7$ure of Na_2 HPO_4 and C_6 H_{11} NaO_7 .

Various Cocentration of corrosion inhibitor were made 20ppm,40 ppm,60ppm mixture of Na_2 HPO_4 and C_6 H_{11} NaO_7 .

After preparing the specimen, measuring it, and recording W1, the specimen was clamped and immersed in a 20 ppm concentration of corrosion inhibitors. After 1 day of immersion at medium velocity and 25°C, the immersion specimen was extracted and washed by washing it under flowing tap water and cleaning it with a soft brush

The plate were then soaked in benzene for 5 minutes to ensure corrosion agents were removed from the metal surface. After immersing the specimens in ethanol and drying them in a discator, the weights were expressed as W2. the treatment uses concentrations of (40, 60, and 80 ppm) and immersion for 2, 3, and 5 days at temperatures of (45, 70, and 95)°C

Table 3,

The chemical Composition for Carbon Steel

Fe	Si	Mn	Ni	Mo	Co	Al	Cr	Cu	C	S	HB
74	2.3	8.9	2.6	3.4	2.7	1.1	2.4	0.9	1.2	0.5	300

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Table 4

Sample Series	**Time /day**	**Conc. In ppm**	**Weight/w1 in gram**	**Weight/w2 in gram**	**Δw**	**Surface area (cm)2**	**C.R. in gmd**
1	1	**15**	48.65	48.6515	0.0015	0.0097	0.1546
2	1	35	48.65	48.6513	0.0013	0.0097	0.1340
3	1	55	48.64	48.6411	0.0011	0.0097	0.1134
4	1	75	48.64	48.641	0.001	0.0097	0.1031
5	2	15	48.65	48.6519	0.0019	0.0097	0.0979
6	2	35	48.65	48.6518	0.0018	0.0097	0.0928
7	2	55	48.7999	48.8009	0.001	0.0097	0.0515
8	2	75	48.7999	48.8007	0.0008	0.0097	0.0412
9	3	15	48.65	48.6518	0.0018	0.0097	0.0619
10	3	35	48.64	48.6417	0.0017	0.0097	0.0584
11	3	55	48.64	48.641	0.001	0.0097	0.0344
12	3	75	48.7999	48.8006	0.0007	0.0097	0.0241
13	5	15	48.6423	48.6438	0.0015	0.0097	0.0309
14	5	35	48.64	48.641	0.001	0.0097	0.0206
15	5	55	48.83	48.8304	0.0004	0.0097	0.0082
16	5	75	48.83	48.8302	0.0002	0.0097	0.0041

The effectiveness of a solution of corrosion inhibitors and scale dispersants (sodium gluconate and sodium phosphate) was measured by using make-up water without corrosion inhibitor, then calculating the corrosion rate for (1,2,3, and 5) days with corrosion inhibitor, as seen in Fig. (3), and chemically analyzing make-up water and inhibited water
Rate of corrosion of Carbon Steel in Mixture of Sodium Gluconate And Sodium Phosphate at Different
Concentration and 30 °C Temperature.The action of sodium phosphate as a corrosion inhibitor means that a film of Iron Phosphate
($Fe_2(PO_4)_2$) is formed on the specimen's surface to passivate and avoid corrosion. as shown in eq.

$$2Na_2HPO_4 + 3Fe + 2H_2O \rightarrow Fe_3(Po_4)_2 + 4NaOH + H_2$$

The findings show that immersing the specimen in a corrosion inhibitor mixture for five days at a concentration of 30-40 ppm resulted in a lower corrosion rate than immersed for one day. As seen in Table (4) and Fig. 1, the relationship was linear, meaning the corrosion rate decreased as concentration and time increased (4).

The scale effect of Sodium Glocunate

By using Sodium Gluconate as Scale inhibitor (T.D.S.) would be reduced from 2900 ppm to 290 ppm in order to reduce the electrochemical reaction in the deposit and tubes that collapsed. The equation shows their role as a sequestering agent, forming water solution complexes with calcium in alkaline media and with iron in near neutral solutions:

$$2C_6H_{11}NaO_7 + CaCo_3 + H_2O \rightarrow Ca(C_6H_{11}O_7)_2 + NaHCo_3 + NaOH$$

The concentration at 30-40 ppm of sodium glocunate indicates that the corrosion rate decreases for 5 days of immersion as shown in below table
As it is noticed athat concentration of 35-40 ppm of Sodium Gluconate the corrosion rate decreses for five days of dipped plate .At Constant Concentration the corrosion rate decrease with increase in time and will have protective layer .
Corrossion rate= (W2-W1)gm/Surface Area cm2xTime(day)

Table 5

Test no.	Time /day	Temp. in °C	Weight/ w1 in gram	Weight/w2 in gram	Δw	Surface area (cm)	*C.R. in gmd
1	1	30	48.2732	48.2717	0.0015	0.0094	0.159574
2	1	55	48.273	48.2709	0.0021		0.223404
3	1	80	48.2664	48.2638	0.0026		0.276596
4	1	95	48.2632	48.2614	0.0018		0.191489
5	2	30	48.4231	48.4218	0.0013		0.069149
6	2	55	48.423	48.421	0.002		0.106383
7	2	80	48.2732	48.2689	0.0043		0.228723
8	2	95	48.2732	48.2713	0.0019		0.101064
9	3	30	48.4231	48.4219	0.0012		0.042553
10	3	55	48.2632	48.2611	0.0021		0.074468
11	3	80	48.2632	48.2599	0.0033		0.117021
12	3	95	48.4532	48.4516	0.0016		0.056738
13	5	30	48.4532	48.4525	0.0007		0.014894
14	5	55	48.2732	48.2722	0.001		0.021277
15	5	80	48.2632	48.2619	0.0013		0.02766
16	5	95	48.4231	48.422671	0.000429		0.009128

3.4. Temperature effect

The rate of corrosion increased at temp(25,50,75) for 24 to 48 hours as temp increasing due to low passivity of corrosion inhibitor at 105 degree the effect will be slightly reduced for 3 to 5 days due to passivation on surface of plate as in table.
The efficiency of mixture of sodiumphosphate and sodium glocunate were (82.3, 86.5,92.8 and 97.1%) at 75 ppm concentration, and at1,2,3,5 days respectively, the corrosion rate of makeup water (raw water) were calculated for 1,2, 3 and 5 days to compare the efficiency of the mixture by applying the equation of the efficiency, where the efficiency increases withtime as shown in the Table (6) and Table (7).

Table 6 The Corrosion Rate of Makeup Water

Time/day	W1(gram)	W2(gram)	Δw	Surface area cm^2	C. R. (gmd)
1	48.1543	48.1596	0.0053	0.0097	0.5463918

2	48.1534	48.1668	0.0134	0.0097	0.6907216
3	48.332	48.3512	0.0192	0.0097	0.6597938
5	48.1555	48.2294	0.0739	0.0097	1.5237113

Table 7 :Parameters of make up and cooling water

Parameter	Make up water	Cooling water
PH	8.2	8.3
TDS	108	604
Alkalinity As ppm	152	174
Conductivity	240	864
Sodium phosphate as ppm	**	**
Sodium gluconate as ppm	-	
	-	80

Table 8,
Efficiency of Mixture of Sodium Phosphate and Sodium Glocunate at 75 ppm.

Time (day)	C.R.(uninhibited) water)	C.R.(inhibited water)	Efficiency%
1	0.55	0.1	81.81
2	0.69	0.09	86.95
3	0.66	0.076	88.48
5	1.52	0.042	97.23

Conclusion

From experimental results using corrosion inhibitor mixture (sodium phosphate as corrosion inhibitor and sodium glocunate as scaledispersant)in cooling tower at 15,35,55 and 75 ppm concentration ,one concludes that at 75 ppm concentration of mixture and at temp. above 75 °C and for 5 days is more efficiently in cooling tower treatment to format passive film and decrease the
corrosion rate.The Cooling tower efficiency can be increased by studying the equipments installed, make up water parameter, installing side stream filter if high turbidity problem persist, automatic chemical feed dosing system, checking microbial activity at regular intervals

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REFERENCES

[1] The Gazette of India, Ministry of Environment, Forest and climate change, notification, New Delhi,The 07th December, 2015.

[2] Natural draft cooling towers pictures; https://www.fansct.com/en/natural-draft-cooling-towers/

[3] Induced draft cooling towers pictures; https://2.bp.blogspot.com/-kObAc8pa9Eo/VrNt-HBnkSI/AAAAAAAAIFE/UePnEq1GlNQ/s1600/induced%2Bdraught%2Bcross-flow%2Bcooling%2Btower.png

[4] Forced draft cooling tower pictures; https://www.electrical4u.com/cooling-tower/

[5] Forced draft cooling tower pictures; https://www.indiamart.com/proddetail/forced-draft-cooling-tower-14463951488.html

[6] Perry RH, Green DW (2008) Psychrometry, evaporative cooling, and solids drying. In: Perry RH, Green DW, Maloney JO (eds) Perry’s chemical engineers’ handbook. McGraw-Hill, New York Google Scholar

[7] Recovery of additional cost incurred due to abnormal increase in water charges, before the CERC, www.ntpc.co.in;//www.cercind.gov.in/2014/technical_validation/NTPC121MP.pdf

[8] Abbi YP (2011) Energy audit: thermal power, combined cycle, and cogeneration plants. The Energy and Resources Institute, New DelhiGoogle Scholar

[9] Amit N, Prajapathi P, Singh RP, Khan SA (2015) Air cooled condensers. https://www.slideshare.net/ravi0704/air-cooled-condensers. Accesssed 11 Oct 2018

[10] Bhattacharya K (2016) Water efficiency in thermal power sector: an outline of cooling technology in India. https://cdn.cseindia.org/userfiles/Kalyan-Bhattacharya-2.pdf. Accessed 10 Nov 2018

[11] Burton B (2018) India’s coal power plants are shutting down because they don’t have enough water. In: Climate change—the new economy. http://climatechange-theneweconomy.com/indias-coal-power- plants-shutting-dont-enough-water/. Accessed 13 Mar 2019

[12] Burton B, Fernandes A (2016) Drought hits Indian coal plants and plans. https://endcoal.org/2016/03/drought-hits-indian-coal-plants-and-plans/. Accessed 25 Mar 2019

[13] Carpenter AM (2015) Water availability and policies for the coal power sector. IEA Clean Coal Centre, LondonGoogle Scholar

[14] CEA (2015) Annual performance review of thermal power stations for 2014–15. Central Electricity Authority, Ministry of Power, Government of India

[15] CEA (2018) Committee on optimal energy mix in power generation on medium and long term basis. New Delhi

[16] CEEW (2017) Implications of shared socio-economic pathways for India's long-term electricity generation and associated water demands. Council on Energy, Environment and Water, New DelhiGoogle Scholar

[17] CERC (2014) Central electricity regulatory commission (terms and conditions of tariff) regulations, 2014. Central Electricity Regulatory Commission, New DelhiGoogle Scholar

[18] CoalSwarm (2016) India and coal. In: SourceWatch. Center for Media and Democracy. https://www.sourcewatch.org/index.php/India_and_coal. Accessed 11 Dec 2018

[19] CSE (2014) The state of our power plants. Centre for Science and Environment, New DelhiGoogle Scholar

[20] Engineering ToolBox (2003) Overall heat transfer coefficients for fluids—heat exchanger surface. https://www.engineeringtoolbox.com/overall-heat-transfer-coefficients-d_284.html. Accessed20 Mar 2019

[21] EPRI, California Energy Commission (2002) Comparison of alternate cooling technologies for california power plants economic, environmental and other tradeoffs. California Energy Commission, Palo AltoGoogle Scholar

[22] Gao J, Zhao P, Zhang H et al (2018) Operational water withdrawal and consumption factors for electricity generation technology in China—a literature review. MDPI 10:1–15. https://doi.org/10.3390/su10041181Google Scholar

[23] Hamon group (2018) Natural draft cooling towers. https://www.europages.co.uk/Natural-draft-cooling-towers/HAMON/cpid-5561189.html. Accessed 11 Nov 2018

[24] MoEFCC (2015) Notification on emission standards in coal power plants (Gazette Notification). Ministry of Environment, Forest and Climate Change, Government of India, New Delhi

[25] Muthuraman M (2016) Reduction in power plant specific water consumption. Indian Power Stations -IPS 2016, Noida

[26] Nexant, Inc (2014) Best practices manual for Indian supercritical plants

[27] NITI Aayog (2018) Composite water management index- a tool for water management. New Delhi

[28] Olsson E (2015) Water use in the chinese coal industry. Uppsala University, UppsalaGoogle Scholar

[29] Perry RH, Green DW (2008) Psychrometry, evaporative cooling, and solids drying. In: Perry RH, Green DW, Maloney JO (eds) Perry's chemical engineers' handbook. McGraw-Hill, NewYorkGoogle Scholar

[30] Srinivasan S, Roshna N, Guttikunda SK et al (2018) Benefit cost analysis of emission standards for coal based thermal power plants in India. Center for Study of Science, Technology and Policy, BangaloreGoogle Scholar

[31] Tianyi L, Krishnan D, Sen S (2018) Parched power: water demands, risks and opportunities for India's power sector. World Resource Institute, Washington DCGoogle Scholar

[32] Xinxin Z, Junguo L, Yu T et al (2017) China's coal-fired power plants impose pressure on water resources. J Clean Prod. https://doi.org/10.1016/j.jclepro.2017.04.040Google

Scholar

[33] Zhai H, Rubin ES (2010) Performance and cost of wet and dry cooling systems for pulverized coal power plants with and without carbon capture and storage. Energy Policy 38:5653– 5660. https://doi.org/10.1016/j.enpol.2010.05.013Google Scholar

[34] Zhai H, Rubin ES (2016) A techno-economic assessment of hybrid cooling systems for coal- and natural-gas-fired power plants with and without carbon capture and storage. Environ Sci Technol 50:4127–4134. https://doi.org/10.1021/acs.est.6b00008

[35] Professor Tursuniva Elza Akramovna, Kotova Lyubov Vlentinovna. (2021). Biological Degradation of Wastewater -Ways to Involve Clean Water Supply. Annals of the Romanian Society for Cell Biology, 1209–1216. Retrieved from https://www.annalsofrscb.ro/index.php/journal/article/view/4472