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Modelling and Simulation of Hydro Power Plant using MATLAB & WatPro 3.0

Jahnvi Tiwari
Shri Mata Vaishno Devi University, Electronics & Communication Engineering, Katra (J&K), 182320, India
E-mail: 2011eec30@smvdu.ac.in

Ashish Kumar Singh, Ashish Yadav, Rakesh Kumar Jha
Shri Mata Vaishno Devi University, Electronics & Communication Engineering, Katra (J&K), 182320, India
E-mail: {2011eec05, 2011eec23}@smvdu.ac.in, jharakesh.45@gmail.com

Abstract— Increase in demand of electricity and clean drinking water has produced a chronic need of a promising and reliable technology for the supply of both commodities, which should be entirely based on renewable sources of energy. The authors, in their previous work, had proposed a design of a hybrid power plant which used graphene membrane for power generation using reverse osmosis process. The proposal included removal of arsenic, poorly biodegradable pollutants using TiO_2 nanoparticles. Chlorine production using the process of electrolysis. The plant was also electronically implemented and included pump control, fouling detection modules and decision module for the volume of effluents to be discharged. The performance of a power system is essential to be analyzed for control, stabilization and efficient modelling. In the present research paper, simulation model of the hybrid plant is analyzed. The chemical behavior is analyzed with 'Watpro 3.0' industrial software and turbine governance system is studied via MATLAB. This plant is a potential replacement of chemical purification techniques with high overhead and excess cost. It is a better, efficient, safe and reliable system to produce clean and safe drinking water and electricity simultaneously.

Index Terms— Reverse Osmosis, Graphene Membrane, Chlorine, Electrolysis, Pump Control, Fouling Detection, TiO_2 Nanoparticles.

I. Introduction

One of the major problem in present scenario is power generation, which is the root cause of depletion of fossil fuel. An efficient and effective techno-economic renewable power generation techniques is proposed for trapping energy which is released during the mixing of seawater and freshwater. In consideration of centralized and decentralized frameworks for drinking water regulation in the context of risk management theory and practical challenges. The second most critical problem analyzed here is purification of contaminated water. Chemical purification is analyzed in detail in the paper. The proposed hybrid power and purification plant could be the key for a regular and safe supply of drinking water as well as power. This plant is a boon for regions of the world stricken with water or power scarcity and water contamination. The basic architecture of the proposed plant model is shown in figure 1.

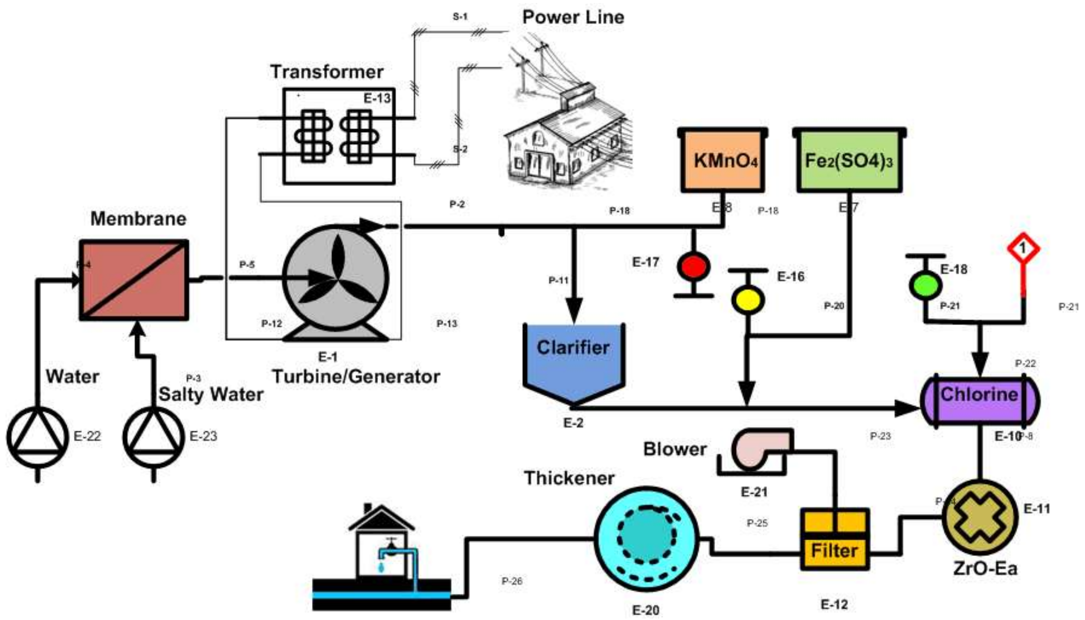

Fig. 1. Hybrid Model

Here, the salty water and fresh water enters the osmosis chamber simultaneously for the process of reverse osmosis. The pressure generated in the chamber is used to rotate the turbine which in turn, generates electricity which is transmitted to the power line. The water from the turbine chamber is then directed to the clarifier, which separated solid from the water and primarily removes some micro-organisms. The clean effluent is treated with $Fe_2(SO_4)_3$ and $KMnO_4$ to reduce metal levels, taste and odor causing compounds.

In processing plant, channels are working as a storage which contains large quantities of fluid which is to be treated. This fluid should be treated as quickly as possible to maintain the flow rate for reducing contamination. Water container collects raw water and its quantity is controlled electrically with advanced chemical governance system and self-excited induction generator. From chemical container the disinfectants are injected in appropriate amount, dosage is calculated and automatically valves opens for a fixed time. As shown in figure 2, the height of water container is 'h' with its area 'A' and let us assume the pressure at top of container be P_i, pressure at out valve be P_o , diameter of orifice be d_o and lower limit of minimum water level be h_l.For simple analysis fluid is taken as incompressible. Applying Bernoulli's equation we get [1].

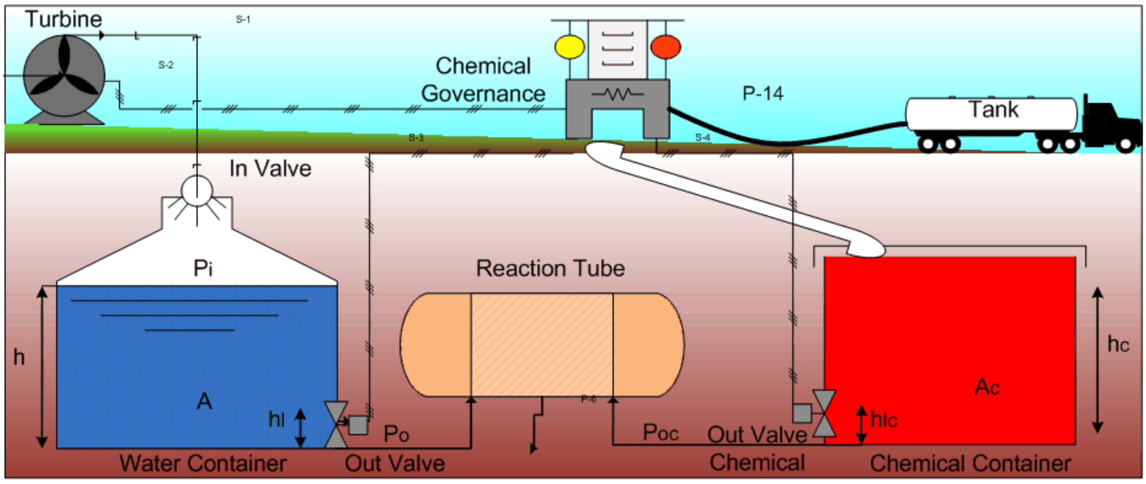

Fig. 2. Model for governance system

$$P_i + \frac{1}{2}\rho v_i^2 + \rho g h_i = P_o + \frac{1}{2}\rho v_o^2 + \rho g h_l \quad (1)$$

Where h_i and v_i is the height and velocity of fluid at top of container respectively whereas h_l and v_o is the height and velocity of fluid at bottom of container respectively. Velocity of fluid at surface is taken to be negligible.

$$P_i + \rho g h(t) = P_o + \frac{1}{2}\rho v_o^2 + \rho g h_l \quad (2)$$

$$\sqrt{2 \times (\frac{P_i - P_o}{\rho} + g \times (h(t) - h_l))} = v_o \quad (3)$$

With this velocity fluid comes out of container. So, the amount of fluid transferred to reaction tube will be required for chemical addition.

$$Fluid\ Mass = Fluid\ Volume \times Fluid\ Density \quad (4)$$

$$M(t) = \rho\, A \times h(t) \quad (5)$$

$$\frac{dM(t)}{dt} = \rho\, A \times \frac{dh(t)}{dt} \quad (6)$$

Rate of change of mass inside container can be expressed as difference of fluid mass entering and mass flow out [1].

$$\frac{dM(t)}{dt} = Mass\ entering\ (In\ Valve) - Mass\ flown\ (Out\ Valve) \quad (7)$$

Mass flow out of container (M_f)

$$= v_o \times Area\ of\ orifice \times \rho \quad (8)$$

$$M_f = \rho v_o \times \pi \frac{d_o^2}{4} \quad (9)$$

Here, we have assumed inlet mass of fluid to be constant M_i.

$$\frac{dM(t)}{dt} = M_i - \rho\pi\frac{d_o^2}{4}\sqrt{2 \times \left(\frac{P_i - P_o}{\rho} + g \times (h(t) - h_l)\right)} \quad (10)$$

From comparing (6) and (10) we get

$$\frac{dh(t)}{dt} = \frac{M_i}{\rho A} - \frac{1}{A}\pi\frac{d_o^2}{4}\sqrt{2 \times \left(\frac{P_i - P_o}{\rho} + g \times (h(t) - h_l)\right)} \quad (11)$$

Similarly, chemical additive is also analyzed and numerical model is constructed using Simulink/MATLAB software GUI system. We have designed a GUI system, shown in figure 4, interconnected to Simulink model, as show in figure 3.

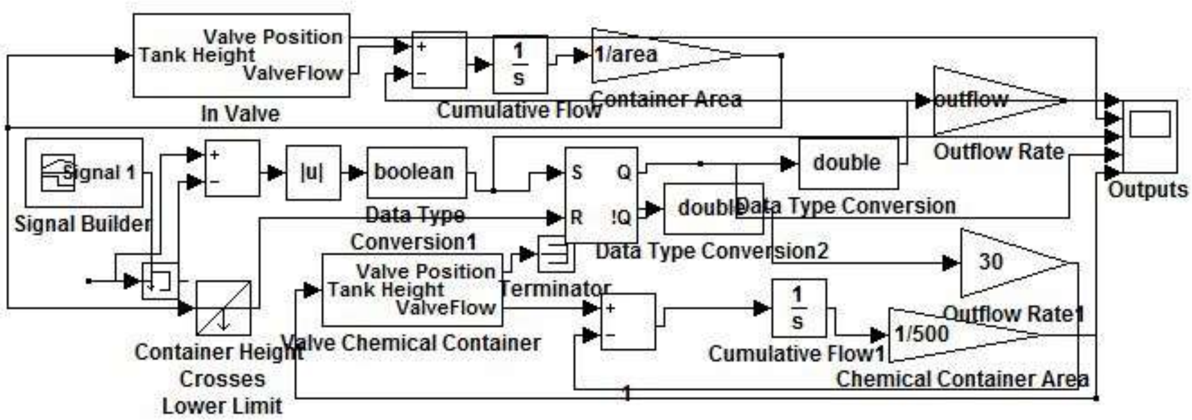

Fig. 3. MATLAB model for chemical control

This plant includes variable fluid container whose dimension is controlled using GUI. Slider are provided to change the area of container, input rate of flow, output flow rate, height of the container and lowest limit unto which system will be force to shut-down. With different parametric value, the rate of diffusion of chemical is different and hence, its level is displayed on the LED screen. Chemical container is also connected with power valve which is controlled using chemical governance system. From simulation point of view parameters are fixed using slider panel, as shown in figure 4.

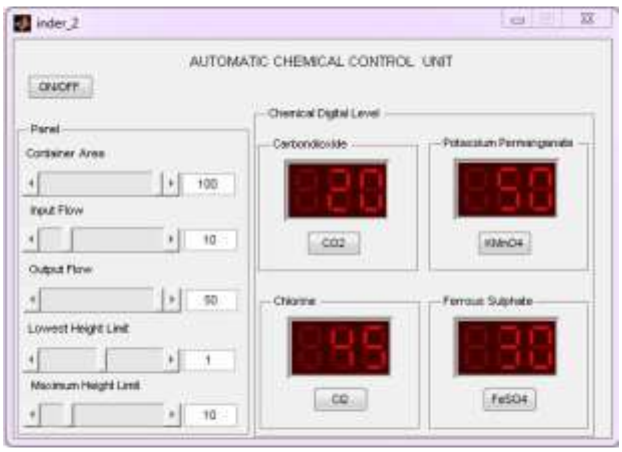

Fig. 4. GUI for chemical additives

II. Related Work

Many research works have contributed to design quality measuring devices for treatment of water [2].The statkraft decided to set up a promising critical components as membranes and pressure recovery devices which lead to the world's first prototype plant in spring 2009 in the southeast of Norway [3].The wastewater treatment plants market in India is expected to grow at a CAGR of 15% till 2018, the "Deep Pond System" in Hyderabad treats 37,854 liters of wastewater per day; this system was implemented as a low-cost wastewater treatment unit in 2004 at the Jawaharlal Nehru Technology University campus in Hyderabad, India[4].

III. Graphical Analysis of Generated Results

Using MATLAB, graph has been plotted and detailed analysis of these graphs is explained in Table 1.

Table 1. Detail Analysis

Time(s)	Observation and conclusion
0 - 45	Inlet valve to fluid container is ON, as a result of which, container height keeps on increasing. Out valve status is OFF and flush pulse is not active. Amount of chemical calculated and injected automatically by GUI decrease the level of chemical.
45 - 49.5	Container reaches its maximum value i.e. 10 m and Input valve is automatically closed i.e. transition from ON to OFF. Flush pulse is not active and out valve status remains constant in OFF mode. GUI transfer chemical in appropriate amount hence level decrease.
49.5 - 50	Container is at its maximum and flush pulse is deactivated, input valve status changes from OFF to ON as a result of ON out valve. Chemical level still keeps on decreasing i.e. chemical is injected.
50 - 53	Container fluid level starts decreasing as out valve is in ON mode while input value is ON but with different flow rate. Flush pulse gets active as chemical additive matches fluid requirement. Chemical level starts increasing.
53 - 72.3	Container fluid level keep on decreasing with input valve ON. Out valve status is ON with rise in chemical level. Flush pulse not triggered.
72.3 - 150	Container fluid level start increasing and input valve status is ON with output valve switched OFF. Decrease in level of chemical occurs with flush pulse to be deactivated.

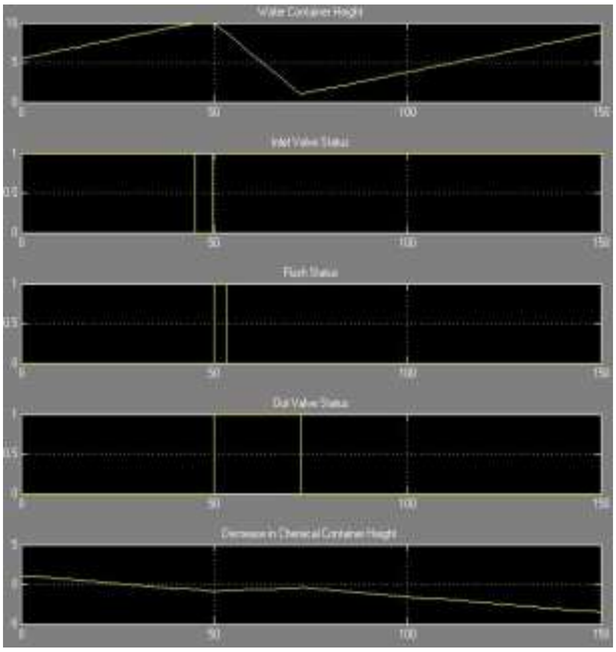

Fig. 5. Graphical Status of Chemical Governance System

IV. Chemical Analysis using WatPro 3.0

Chemical addition to water is again a very important work to be done with exact concentration value dosage of additives. This can be dreadful if human error occurs which is highly probable. Therefore, an automated system is developed for governance of concentration of chemical additives with appropriate fluid concentration. Governance system is simulated using WatPro [5] and analyzed for better results, so for small prototype we have assumed some parameters and observed the result. Watpro software model of chemical addition is show in figure 6. From figure 6, different block position is expressed: A1 (Raw Water Influent), A3 (Measurement), B3 (Channel), C3 (Flocculator), D1 (Addition Ferrous Sulfate), D3 (Membrane), E3 (Settling Basin), F1 (Addition CO2), F3 (Transfer/Distribution Pipe), G1 (Potassium Permanganate), G3 (Filtration), H3 (Ultraviolet Contactor), H4 (Calcium Hydroxide) I1 (Disinfect Addition Chlorine), J3 (Measurement), K3 (Final Treated Water Effluent). We will discuss independently every single step involved for water purification.

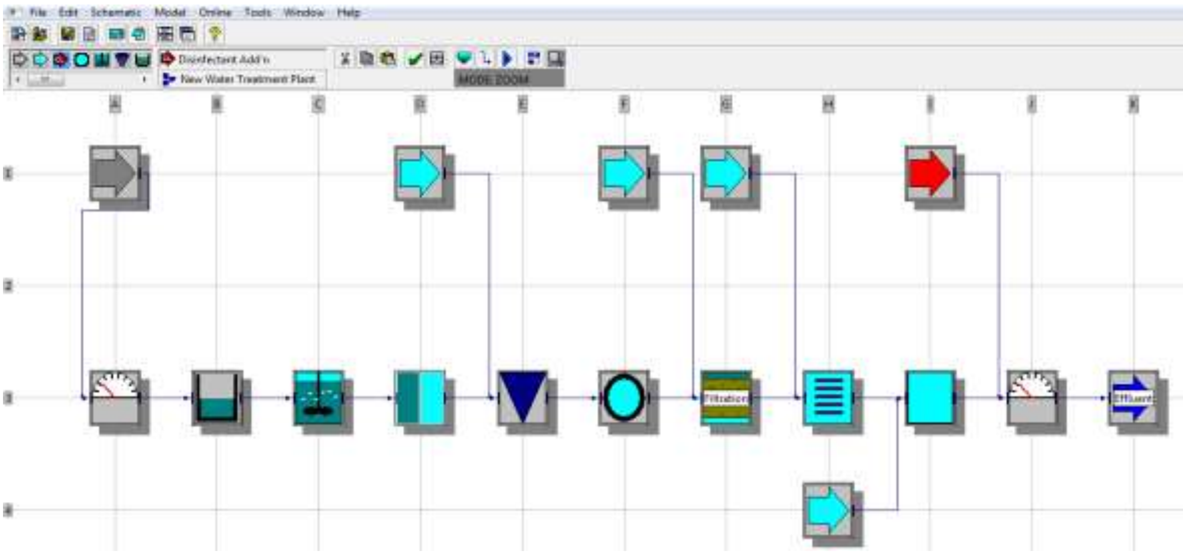

Fig. 6. Chemical Analysis

A1 Raw Water Influent

The outlet of turbine is connected to advance electronic system which is designed to remotely access the chemical and disinfectant additives. Small prototype of this hybrid plant is stimulated using WatPro 3.0 a water treatment simulation software. For simulation propose, raw water influent which is further transferred to small channel for suspension of heavy sediment.

A3 Measurement

Raw water which is to be treated is measured for different properties. We have assumed input flow rate to be 64800 m^3/day at a temperature of 10 ^{0}C with other parameters stated in table 2. It can be observed that water pH is around 7.5 and hardness 100 mg/L which contributes to the scaling of water boiler.

Table. 2. Initial properties of contaminated water

Property	Value	Unit
Flow	64800	m^3/day
Temperature	10	^{0}C
pH	7.5	
Turbidity	0.5	NTU
UV254	0.1	1/cm
Total Organic Carbon	3	mg/L
Carbonates (aq)	218.17	mg/L
Calcium	80	mg/L
Magnesium (aq)	20	mg/L
Alkalinity	100	mg/L
Hardness	100	mg/L
Ammonia as N	5×10^{-2}	mg/L
Bromide	0.10	mg/L
Giardia	1.00	cysts/100L

Turbidity allowed is maximum 5 NTU. Above 5 NTU, consumer acceptance decreases. The permissible limit of pH is 6.5 to 8.5, beyond this range it affects mucous membrane and water supply systems. Presence of calcium carbonates which is also the measure of hardness can be maximum 300 mg/L. Above this level Encrustation in water supply structure takes place and it also has adverse effects on domestic use. Alkalinity measured in mg/L, can be maximum upto 200. Beyond this limit taste becomes unpleasant.

B3 Channel

Fluid container is used for storing water and to control the rate of flow of fluid toward pipeline. In MATLAB model we have assumed a variable channel whose length and area can be adjusted using GUI.

Table. 3. Water storage tank dimension

Property	Value	Unit
Length	10.0	M
Depth	10.0	M
Width	10.0	M

C3 Flocculator

Flocculator chamber is used for separating small particles. In this chamber, a process take place where colloids are separated from suspension in form of flakes. Turbidity of raw water is decreased from 0.5 to 0.2 NTU which

Table. 4. Turbidity details

Property	Value	Unit
Volume	200.00	m^3
Turbidity	0.20	NTU

D1 Addition Ferrous Sulfate

Distribution pipe drives water to chamber for treatment with $Fe_2 (SO_4)_3$ for removal of heavy metals. It is more efficient coagulant which removes chromium (89.58%), Ni (99.73%), Zn (68.42%) and Mn (35.29%) from fluid with 13 mg/L dosage [6].

Table. 5. Chemical amount of $Fe_2 (SO_4)_3$

Property	Value	Unit
Chemical Dosage	22.5	mg/L

D3 Membrane

Molecular weight cut-off can be defined as the molecular weight at which 80% of the analytes (or solutes) are prohibited from membrane diffusion. Here, user specifies the water production percentage through membrane and optionally the effluent turbidity [7].

Table. 6. Fluid properties at membrane

Property	Value	Unit
Molecular weight cut-off	500.0	g/mol
Operating pressure	300.0	kPa
Recovery	30.00	

E3 Settling Basin

Settling basin is used for settlement and to reduce the outlet turbidity.

Table. 7. Turbidity details

Property	Value	Unit
Volume	200.00	m^3
Measured Turbidity	0.15	NTU

F1 Addition CO2

CO_2 addition in water causes leaching of various elements which could be hazardous to life. It is used to reduce the effect of arsenic, zinc, lead etc. Raw water absorbs CO_2 and due to chemical reaction reduction in pH and carbonate ion concentration is observed.

Table. 8. Carbon dioxide dosage

Property	Value	Unit
Chemical Dosage	10.00	mg/L

F3 Transfer/Distribution Pipe

Dimension of pipe is estimated for appropriate addition of chemical additives which reduces the chance of excess chemical concentration.

Table. 9. Dimension of pipeline

Property	Value	Unit
Length	100.00	m
Diameter	1.00	m

G1 Potassium Permanganate ($KMnO_4$)

This is used for the removal of taste and odor from flowing water, to oxidize a wide variety of inorganic and organic substances and to completely inactivate bacteria. Water borne diseases are major threat which can be decreased by controlling dosage of $KMnO_4$ from 0.25 to 20 mg/L [3].

Table. 10. Dosage of $KMnO_4$

Property	Value	Unit
Dosage	4.00	mg/L

G3 Filtration

Filter type used is conventional because it follows coagulation and sedimentation and it can be used for variable turbidity and bacteria level. Fluid flow rate should be maintained, if flow rate is very high sediments will cross the pores.

Table. 11. Filtered output fluid

Property	Value	Unit
Volume	300.00	m^3
Measured Turbidity	0.1	NTU

H3 Ultraviolet Contactor

It is the most commonly used for disinfection of water by causing damage to the genetic structure of bacteria, viruses, and other pathogens, making them incapable of multiplication [8]. Non-biodegradable substance is treated in presence of titanium oxide nanoparticle [9].

Table. 12. Properties of fluid after ultra violet treatment

Property	Value	Unit
Log Inactivation Giardia	2.00	log(10)
Log Inactivation Virus	4.00	log(10)
Log Inactivation Cryptosporidum	2.00	log(10)

I1 Disinfect Addition Chlorine

In contaminated water it is necessary to kill sever harmful microorganisms and for this chlorination of water is necessary. In this plant, chlorine is produced using brackish water for electrolysis and generating free chlorine. It reacts with ammonia if present in raw water and forms chloramines. For simulation purpose, 2 mg/L chlorine dosage is used for chlorination.

Table. 13. Fluid chlorination dosage

Property	Value	Unit
Chemical Dosage	2.00	mg/L

For chlorination the main disinfecting agents can be produced from the naturally occurring ions found in the waste salty water (unpressurised water) itself as stated by Chen-Yu Chang Yi-Tze Tsai [10].

J3 Measurement

This indicator flashes output and treats fluid with appropriated chemical addition, stabilization and mineralization. Rate of flow is decreased to maintain the flow in pipeline and for reaction time. Drinking water pH is around 7 which is near to ideal. The high energy associated with short wavelength UV energy, primarily at 254 nm, is absorbed by cellular DNA can damage the DNA of living organisms by creating nucleic acid dimers [11].

Table. 14. Properties of treated fluid

Property	Value	Unit
Flow	19440	m^3/day
Temperature	10	^{0}C
pH	7.01	
Turbidity	0.1	
UV254	2.31×10^{-2}	1/cm
Total Organic Carbon	0.69	mg/L
Carbonates (aq)	34.39	mg/L
Calcium	35.32	mg/L
Magnesium (aq)	0.39	mg/L
Alkalinity	13.37	mg/L
Hardness as $CaCO_3$	35.70	mg/L
Ammonia	5×10^{-2}	mg/L

Manganese (as Mn) mg/L can be nearly 0.3-0.4. Beyond this range taste/ appearance are affected which has adverse effect on domestic uses and water supply structures.

K3 Final Treated Water Effluent

Finally raw water after crossing numerous process gives pure and safe drinking water. One of the major factor is turbidity which is reduced from 0.5 to 0.1 NTU. It is measured by scattering of light, if intensity is low turbidity is less while, high intensity leads to high turbidity.

Table. 15.

Disinfection	Criteria	Status	Result	Unit
Req. Giardia Reduction	4.00	OK	4.50	log(10)
Req. Virus Reduction	5.00	OK	6.00	log(10)
Req. Crypt Reduction	2.00	OK	4.00	log(10)
Max Chlorine Allowed	4.00	OK	2.00	mg/L
Max Turbidity Allowed	0.50	OK	0.10	NTU

V. Conclusion

The paper here proposes and analyses an efficient, productive hybrid plant for power generation and water purification. The central idea is to combine two separate efficient entities for the purpose.

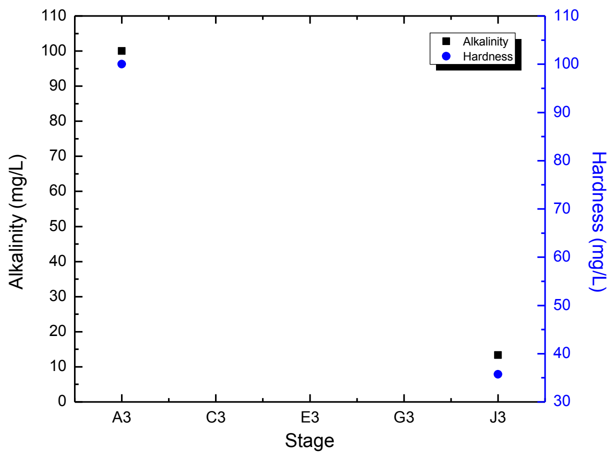

Fig. 6. Alkalinity and Hardness of water at different stages

Electricity production with purification of water with this eco-friendly advance system is a cost effective proposed solution for lack of clean water and electricity. Raw drinking water is finally converted to pure form with proper balancing of hardness and alkalinity. This can be shown in figure 6. Water pH is another important parameter for drinking. Initially raw water is taken whose pH was not safe therefore due to treatment through different stages its pH value is brought down towards neutral. Treatment process on different versus pH is shown in figure 7.

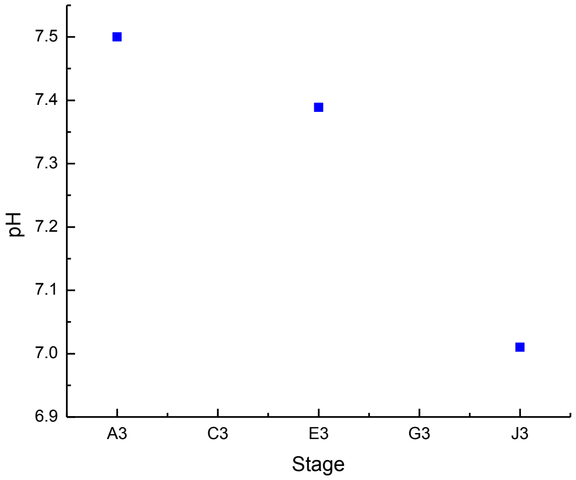

Fig. 7. pH of water at different stages

Water turbidity is measure of water clarity. Here different filtration technique is used for the proper separation of suspended particles from water and make it pure enough to drink. This suspended particle are not visible from naked eyes and from below figure 8, it can be seen that finally turbidity is 0.1 NTU.

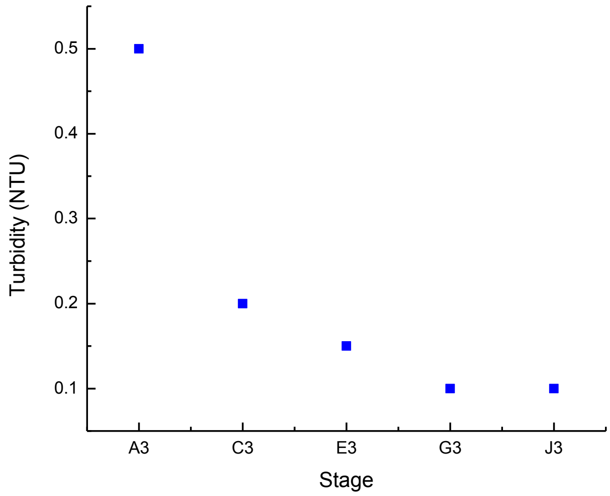

Fig. 8. Turbidity of water at different stages

This system is designed to operate in any situation irrespective of fault occurrence like scaling, fouling and clogging. WatPro 3.0 and MATLAB simulated result shows that raw water is treated and finally can be used for safe drinking water. The automated chemical and valve control reduces the risk of human error and over or under dosing of effluents. This also reduces the manpower to be employed for the smooth working of the hybrid hydro power plant.

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Authors' Profiles

Jahnvi Tiwari was born on February 9, 1993. She is expecting her bachelor of technology degree from Shri Mata Vaishno Devi University, India, in 2015. In 2014, she received Summer Undergraduate Research Grant for Excellence (SURGE) from Indian Institute Of Technology, Kanpur. Her research interests include systems designing, implementation, analysis and operation of embedded systems. High efficiency Solar cell, water treatment plants power generation and optimization. Peer to peer network software development, tapestry and JXTA. She has publication in field of solar energy (Journal of Energy), water purification.

Ashish Kumar Singh was born on October 3, 1992. He is expecting his bachelor of technology degree from Shri Mata Vaishno Devi University, India, in 2015. His research experience include analysis and Impact of ART and DPC on AODV Routing Environment for Dynamic Network using QualNet 7.1 at Indian Institute Of Technology, Varanasi in 2014 and Ge-content dependent efficiency of Si/SiGe heterojunction solar cell analysis at Indian School Of Mines, Dhanbad in 2013. He has contributed with his

publication in several fields like photonics, silicon solar cells, autonomous irrigation system and power generation.

Ashish Yadav was born on May 26, 1994. He is expecting his bachelor of technology degree from Shri Mata Vaishno Devi University, India, in 2015. He has experience as an intern at Visvesvaraya National Institute of Technology, Nagpur in designing, Testing and Verification of ADC Systems using nano-CMOS technology with low power/process design. His interest includes process variation tolerant circuit design, testing and verification of VLSI circuit systems and nano-CMOS technology, low power/process aware VLSI design. He has published in renowned journal and presented papers in various international conference.

Rakesh K Jha: currently an assistant professor in school of electronics and communication department, SMVD University Katra (J&K). He is carrying out his research in WiMAX and Security issues in the laboratory ECED Lab, SMVDU. Involved research topics include WiMAX performance analysis, LBRRA, power optimization and security analysis. He has done B.Tech in Electronics & Communication from Bhopal and M.Tech from NIT Jalandhar, INDIA. Received his PhD degree from NIT Surat in 2013. Published more than 50 International Conference and Journal papers. His area of interest is Wireless communication, Communication System and computer network, and Security issues (Opti System). One concept related to router of Wireless Communication has been accepted by ITU (International Telecommunication Union) in 2010. Received young scientist author award by ITU in Dec 2010 and APAN fellowship in 2011. Also received student travel grant from COMSNET 2012. Dr. Rakesh K Jha is a member of IEEE, GISFI and SIAM, International Association of Engineers (IAENG) and ACCS (Advance Computing and Communication Society).

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