Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Modification of Condenser Nozzle and Cooling Tower Exit Screen to Increase Condenser Performance

Amri Zein[1], Paul A. Taylor[2], Heribertus Dwiyudha[3]

Wayang Windu Geothermal Power Station - Star Energy Geothermal (WW) Ltd, Pangalengan, West Java - Indonesia

[1]amri.zein@starenergy.co.id, [2]paul.taylor@starenergy.co.id, [3]heribertus.dwiyudha@starenergy.co.id

Keywords: Wayang Windu, condenser pressure, nozzle, gas cooling zone, performance, cooling tower

ABSTRACT

The cooling water (CW) design flow to the condenser of Unit 1, 110MWe Wayang Windu Geothermal Power Plant, West Java, as per heat balance is 4639 kg/s. Although this flow was achieved during first commissioning, it reduced quickly in normal operation which caused the condenser pressure to increase above the design pressure of 0.12 bara and resulted in a loss of generation. After investigating the condenser during a major maintenance shutdown in 2003, it was determined that reduction in water flow was caused by fouling of nozzles, particularly those installed in the gas cooling zone. There are two types of gas cooling zone (GCZ) spray nozzle which are full cone nozzle (with upstream bore diameter and down stream bore diameter is 5 mm and 7.5 mm respectively) and flat type nozzle which has progressive opening width from 5 to 8 mm and length 11 mm respectively. Fouling at GCZ nozzles is caused by bugs (or beetles) which pass through the Cooling Tower (CT) exit screens. However, no significant fouling of the main condensing zone (MCZ) spray nozzles was observed which indicated that bugs will not cause fouling in 20 mm diameter nozzles. Over the next 2 years, Star Energy Geothermal (WW) Ltd (SEGWWL) attempted to significantly improve the management of cooling tower screen design and cleaning, but cooling water flow reduction continued to occur albeit at a reduced rate.

SEGWWL conducted an engineering study and recommended that condenser performance can be significantly improved by enlarging the diameter of full cone type GCZ nozzles and installing fine wire mesh at the Cooling Tower (CT) exit screen which will act as a filter of bugs or other debris before flowing to condenser. The modification of full cone type GCZ nozzle's diameter and fine wire mesh installation which was completed in 2005 improved the condenser performance and stopped the reduction of CW flow caused by fouling. The annual average condenser pressure reduced from 0.13 Bara to 0.11 bara. The average cooling water flow is increased by approximately 3.5%. Furthermore, the improvement in condenser performance increased the average power generation by approximately 1 to 2 MW.

1. INTRODUCTION

Wayang Windu Geothermal Power Plant Unit 1, which has a capacity of 110 MWe, was the largest single cylinder turbine in the world when it was commissioned in May 2000. Electricity from the Power Plant is supplied to PLN (Indonesia's state electricity company)

1.1 Process Overview

The separated main steam containing some non-condensable gases is supplied from two 36" steam lines to a 48" header after any liquid droplets are removed from the steam through the steam scrubbers. The design steam supply conditions are 10.6 bar absolute at 182°C and flow of 211 kg/second .

The turbo generator is supplied from the steam header via a 44 inch line through steam strainers, steam turbine main stop valves and steam flow control valves. To control the output of the turbo generator, the turbine governor operates the steam flow control valves.

The FUJI 110 MW steam turbine is directly coupled to the FUJI two-pole 137.5 MVA 13.8 kV generator. The steam turbine is a single casing, double-flow, reaction type with eight stages in each flow. The generator is three phase 50Hz air cooled with forced air cooling using water.

The generator electrical output is supplied to the PLN grid via a generator transformer that increases the voltage to 150kV. An additional connection to the generator output is used to supply the power station electrical plant through a 13.8 kV to 6.3 kV unit transformer. A circuit breaker and an earthing switch is installed between the generator and transformer. The generator can be synchronized to the PLN grid using low voltage or the high voltage circuit breakers.

After doing the work in the turbine, the steam is exhausted to a direct contact spray type condenser mounted beneath the turbine. Cooling water delivered from the cooling tower through the condenser spray nozzles is used to condense the steam through direct contact. The condenser cooling water and condensed turbine exhaust steam collects in the condenser hotwell as condensate. Two 50% duty hotwell pumps remove condensate from the hotwell and deliver it to the cooling tower.

In the cooling tower, heat is removed from the condensate by the air flowing through the tower. The cooling tower is a counter flow type forced draught type with motor driven fans to provide the forced draught.

The loss of cooling water that is carried away in the water vapor plume of the cooling tower is not enough to counter the additional condensed steam. A cooling tower level control system is used to remove excess condensate to the Steam Above Ground System (SAGS) condensate re-injection system.

Non condensable gases are collected and removed from the condenser by the gas removal system. The gas removal system is a hybrid system using steam ejectors and liquid ring vacuum pumps to remove non-condensable gases and deliver them to the cooling tower. The steam supply to gas removal system is from the main steam header by a 10" supply line separate to the turbo generator supply. The non-condensable gases are discharged to the cooling tower beneath the fans and are carried away in the thermal plume of the cooling tower.

An auxiliary cooling water system supplied from the cooling tower basin outlet pipe is used for cooling turbine lube oil, generator air coolers and the gas removal system inter and after condensers. Two 100% duty auxiliary cooling water pumps are installed for circulation of the auxiliary cooling water.

The plant compressed air systems use three rotary screw compressors to supply two general air receivers that supply the instrument air and utility air supplies. Instrument air is supplied via heat less air dryers and filters to control valves and other instruments that require clean dry air. Utility air is supplied via an auto shut off valve that will close if instrument air pressure falls.

Plant fire protections systems include automatic and manual sprinklers, fire hydrants and portable fire extinguishers. Fire detection is by heat sensors and smoke sensors. A diesel and electric fire are installed to supply sprinkle and hydrant systems.

Plant electrical systems use 6.3 kV supplies for major auxiliary plant supplies and 6.3kV/380 V transformers to supply general auxiliary equipment. An 1100 kW emergency generator supplies the 380 V systems. DC systems of 125V and 230V use batteries and battery chargers for essential supplies. Essential no-break AC equipment such as the DCS plant control systems are supplied by a UPS that uses rectifiers, batteries and inverters.

The plant is controlled from a central control room adjacent to the turbine hall. A distributed control system is used for all start, stop, and on line operations and monitoring. Automatic turbine start, synchronizing, loading, shut down are achieved by use of the plant control systems. Automatic control of critical and important process conditions such as the SAGS power station interface steam pressure is included in the distributed control system functions. Remote switching of electrical equipment and automated sequential starting and stopping of major auxiliaries is another feature available to the operators in the control room.

1.2 Condenser Nozzle Fouling Problem

During first commissioning, cooling water flow (as per heat balance is 4639 kg/s) was achieved according to design. However, the flow reduced quickly in normal operation which caused the condenser pressure to increase above its design pressure of 0.12bara. After investigating the condenser during a major maintenance shutdown in 2003, it was determined that reduction in water flow was caused by fouling of nozzles, particularly those installed in the gas cooling zone. There are two types of gas cooling zone (GCZ) spray nozzle which are full cone nozzle (with upstream bore diameter and down stream bore diameter of 5 mm and 7.5 mm respectively) and flat type nozzle which has progressive opening width from 5 to 8 mm and length 11 mm respectively. Fouling at GCZ nozzles is caused by bugs (or beetles) which pass through the Cooling Tower (CT) exit screens. However, no significant fouling of the main condensing zone (MCZ) spray nozzles was observed which indicated that bugs will not cause fouling in 20 mm diameter nozzles.

2. ENGINEERING STUDY

Due to limited resources for heat transfer study and existing power plant system design, SEGWWL conducted engineering study based on available design data and experimental method. The basic principles are to assure current cooling water pressure is adequate to supply the cooling system in condenser and the water droplets from the nozzle can extract heat from the hot condensate effectively.

Engineering study scopes was as follow:

- Study of cooling system design calculation
- Measure nozzle flow rate
- Checking head loss of CT exit screen
- Review technical query from Fuji Electric
- Calculate flow rate and propose new design of condenser nozzle

2.1 Study of Cooling System Design Calculation

Study of cooling system design calculation is to know cooling system design parameter and data which were used in the design. It will also help the designer to do some simulations if some parameters are changed or added to system. Therefore, it gives advantages for flow simulation subject.

2.2 Measuring Nozzle Flow Rate

To conduct nozzle flow rate measurement, SEGWWL prepared testing tools and modified bore diameter or swirl of nozzle by using machining processes. There were 6 (six) test samples provided for this purpose as follows:

- Flat type nozzle (existing)
- Full cone nozzle with downstream bore diameter 7.5 mm with 4 swirls (existing)
- Full cone nozzle with downstream bore diameter 10 mm with 4 swirls
- Full cone nozzle with downstream bore diameter 10 mm and enlarged cyclone section area
- Full cone nozzle with downstream bore diameter 10 mm and 3 swirls only
- Full cone nozzle with downstream bore diameter 10 mm and 2 swirls only
- Full cone nozzle with downstream bore diameter 10 mm with 4 swirls and bore eccentric defect

Water droplets figure for each testing was compared with water droplet figure of existing nozzle to assure the water droplets of nozzle still can transfer heat of hot condensate effectively.

2.3 Checking Pressure Drop at CT Exit Screen

Checking pressure drop at CT exit screen was needed to assure pressure drop due to CT exit screen and proposed additional wire mesh at CT exit screen will not give significant affect to cooling tower exit pressure.

2.4 Review Technical Query from Fuji Electric

Fuji Electric as the condenser designer was requested to submit technical query about nozzle design in condenser system. Review of technical query from Fuji Electric is to have Fuji Electric consideration about nozzle modification and to optimize nozzle design in condenser system.

2.5 Calculate Flow Rate and Propose New Design of Condenser Nozzle

After checking calculation of cooling system design and measuring nozzle flow rate, SEGWWL calculated cooling flow rate and conducted simulation data to assure current cooling water pressure is adequate to supply cooling water system in condenser with condition when condenser nozzles are modified and additional wire mesh is installed at CT exit screen. Besides, water flow rate should be designed not more than maximum water flow rate transferred by hot well pumps (5660 kg/s for 2 units pump running).

3. RESULT AND DISCUSSION

By using mechanical fluid principle, study of cooling system design calculation delivered cooling water design parameter and data needed for flow modification subject.

Measuring of existing flat type nozzle flow capacity showed that design data and experimental data had only a slight difference of 2.94 % at design head pressure 0.584 barg (see Table 1 and Figure 1a) whereas design flow is 0.406 kg/s and experimentation flow is 0.418 kg/s. However, it was difficult to conduct modification of flat type nozzle due to restriction of its existing shape.

Measuring of existing full cone type nozzle (with downstream bore diameter 7.5 mm and 4 swirls) flow capacity shows that design data and experimental data had only a slight difference of 2.33 % at design head pressure 0.584 barg (see Table 1 and Figure 1b) whereas design flow is 0.423 kg/s and experimentation flow is 0.413 kg/s. Due to its simple shape, the bore of full cone type nozzle could be enlarged to a bigger diameter (10 mm) for experimentation.

Measuring of full cone type nozzle (with downstream bore diameter 10 mm and 4 swirls) flow capacity shows that modified nozzle flow is 0.604 kg/s at design head pressure 0.584 barg (see Table 2 Modification A and Figure 2) and the droplet size is almost similar with existing full cone droplet size.

Measuring of full cone type nozzle (with downstream bore diameter 10 mm and enlarged cyclone section area of 4 swirls) flow capacity shows that modified nozzle flow is 0.764 kg/s at design head pressure 0.584 barg (see Table 2 Modification B and Figure 2) and the droplet size is bigger than existing full cone droplet size.

Measuring of full cone type nozzle (with downstream bore diameter 10 mm and 3 swirls) flow capacity shows that modified nozzle flow is 0.752 kg/s at design head pressure 0.584 barg (see Table 2 Modification C and Figure 2) and the droplet size is different with existing full cone droplet size.

Measuring of full cone type nozzle (with downstream bore diameter 10 mm and 2 swirls) flow capacity shows that modified nozzle flow is 0.794 kg/s at design head pressure 0.584 barg (see Table 2 Modification D and Figure 2) and the droplet size is different with existing full cone droplet size.

Based on measurement data, further flow capacity measurements of full cone nozzle with downstream bore diameter 10 mm were conducted to get accurate data by using more samples including samples with bore eccentric defects. The calculated average flow at design head pressure 0.584 barg was 0.58 to 0.6 kg/s and bore eccentric defect did not give significant affect to flow rate (see Table 3, Figure 3 and Figure 4).

Checking pressure drop at CT exit screen was conducted by comparing design pressure drop data and measuring pressure difference between inlet and outlet of CT exit screen. The result showed that design pressure drop data was higher than measured pressure difference between inlet and outlet of CT exit screen. It was assumed that the designer included a margin to anticipate higher pressure drop which could occur due to fouling at CT exit screen. It was proposed to install additional fine wire mesh at CT exit screen (wire diameter 1 mm, opening area 3.23x3.23 mm2) to filter particles with size smaller than upstream bore diameter of full cone nozzle (d = 5 mm).

With measurement data obtained and review completed of technical query from Fuji Electric as condenser designer, flow simulation calculations were conducted to assure current cooling water pressure is adequate to supply cooling water system in condenser with modified GCZ nozzles and installation of additional wire mesh at CT exit screen. Flow simulation calculation is shown in Table 4.

The modification of full cone type GCZ nozzle's diameter and installation of fine wire mesh which was completed in 2005 improved the condenser performance and stopped the reduction of CW flow caused by fouling (see Figure 5 & Figure 6). The annual average condenser pressure reduced from 0.13 Bara to 0.11 bara. The average cooling water flow is increased by approximately 3.5%. Furthermore, the improvement in condenser performance increased the average power generation by approximately 1 to 2 MW.

ACKNOWLEDGEMENT

Many thanks to Star Energy Geothermal (Wayang Windu) Ltd. for all support and permission to publish this work.

REFERENCES

Fuji Electric Co.,Ltd.: Operation and Maintenance Manual Wayang Windu Geothermal Power Project Volume 3 (1/41), 2000.

Fuji Electric Co.,Ltd.: As Built Documentation, Unit 1 & Common Equipment, Wayang Windu Geothermal Power (11/31), 2000.

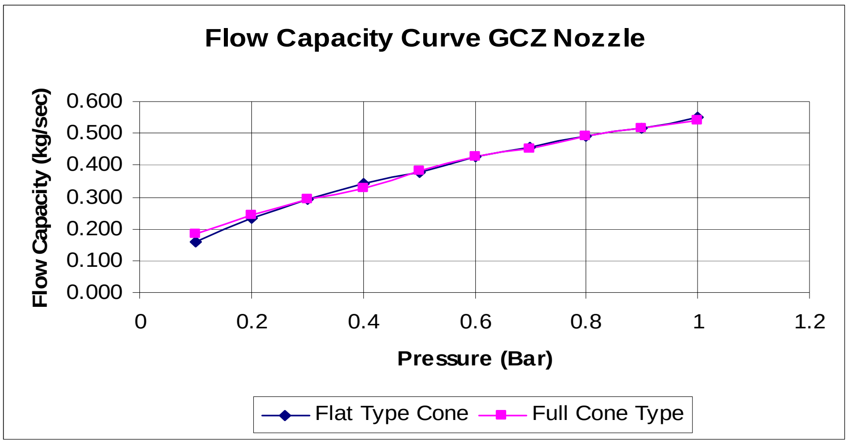
Gerhart P.M., Gross R.J. & Hochstein, J.I.: Fundamentals of Fluid Mechanics, 2nd Edition, 1992.

Moran, Michael J. & Shapiro, Howard N.: Fundamental of Engineering Thermodynamics, 5th Edition, 2004.

Perry, Robert H. & Green, Don W.: Perry's Chemical Engineer's Handbook, 7th Edition, 1997.

TABLE 1.

Nozzle Type	Full Cone		Flat Type	
Pressure (bar)	Flow (kg/min)	Flow (kg/s)	Flow (kg/min)	Flow (kg/s)
0.1	11	0.18	9.5	0.16
0.2	14.5	0.24	14	0.23
0.3	17.5	0.29	17.5	0.29
0.4	19.5	0.32	20.5	0.34
0.5	23	0.38	22.5	0.37
0.6	25.5	0.42	25.5	0.42
0.7	27	0.45	27.5	0.46
0.8	29.5	0.49	29.5	0.49
0.9	31	0.52	31	0.52
1	32.5	0.54	33	0.55



Full Cone Type Original (1a)

Flat Type Original (1b)

FIGURE 1.

TABLE 2.

Nozzle Type	Modification (A)	Modification (B)	Modification (C)	Modification (D)
Pressure (bar)	Flow (kg/s)	Flow (kg/s)	Flow (kg/s)	Flow (kg/s)
0.1	0.28	0.34	0.34	0.35
0.2	0.37	0.46	0.46	0.48
0.3	0.45	0.57	0.55	0.58
0.4	0.50	0.63	0.63	0.66
0.5	0.56	0.71	0.70	0.75
0.6	0.62	0.77	0.76	0.80
0.7	0.65	0.83	0.81	0.85
0.8	0.69	0.88	0.88	0.92
0.9	0.74	0.93	0.94	0.97
1	0.78	0.98	0.98	1.03

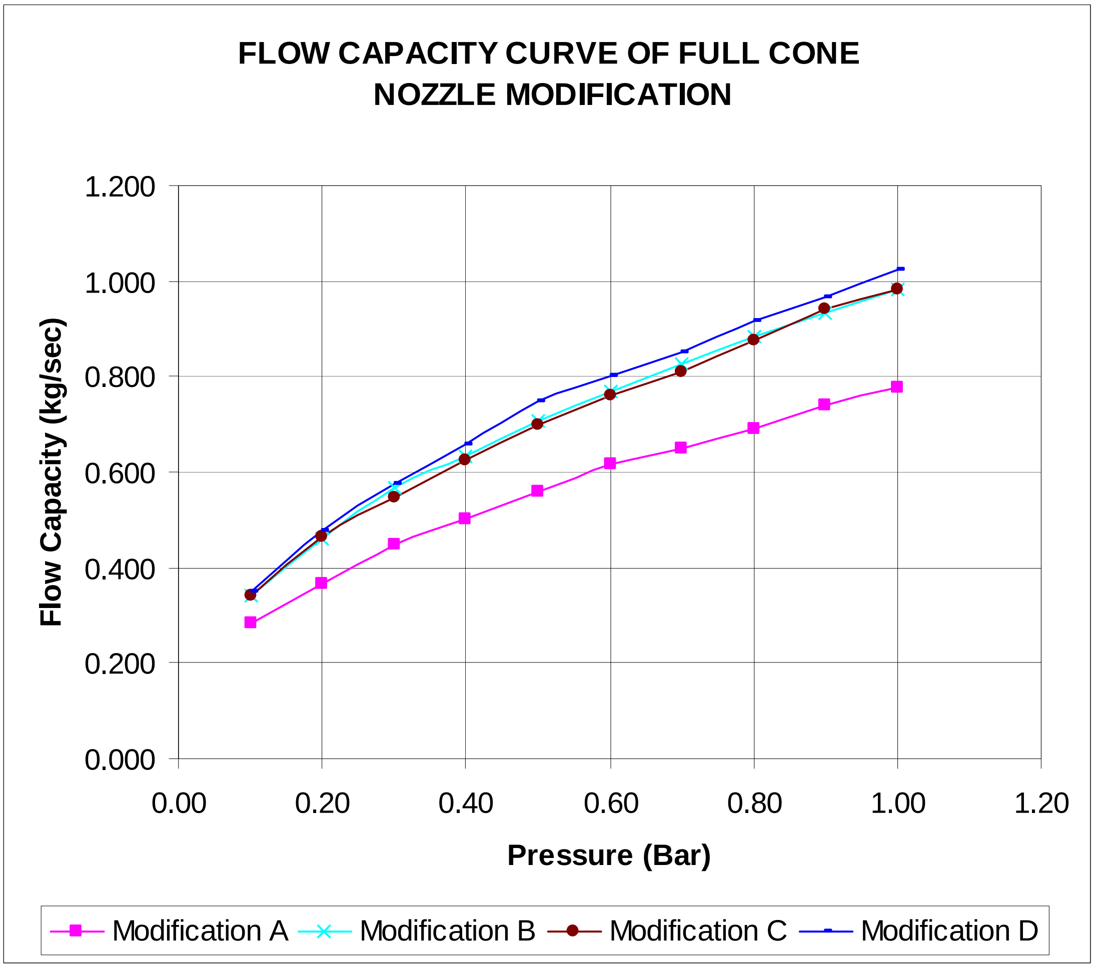


FIGURE 2.

TABLE 3.

Modification Nozzle	1	2	3	4	5	6	7	8	9	10
Pressure (bar)	kg/s	kg/s	kg/s	kg/s	kg/s	kg/s	kg/s	kg/s	kg/s	kg/s
0.1	0.23	0.23	0.23	0.24	0.24	0.23	0.23	0.23	0.23	0.23
0.2	0.34	0.33	0.33	0.33	0.34	0.33	0.33	0.33	0.33	0.33
0.3	0.42	0.41	0.41	0.42	0.43	0.41	0.41	0.43	0.41	0.41
0.4	0.48	0.48	0.49	0.48	0.51	0.48	0.48	0.49	0.48	0.48
0.5	0.56	0.54	0.55	0.53	0.57	0.53	0.54	0.55	0.55	0.53
0.6	0.58	0.58	0.59	0.59	0.63	0.59	0.58	0.60	0.60	0.58
0.7	0.62	0.63	0.64	0.62	0.66	0.63	0.64	0.63	0.63	0.63
0.8	0.69	0.68	0.68	0.68	0.73	0.68	0.68	0.69	0.69	0.68
0.9	0.72	0.73	0.73	0.73	0.78	0.71	0.72	0.74	0.72	0.72
1	0.77	0.76	0.77	0.77	0.83	0.75	0.76	0.78	0.77	0.78

Note:

- Modification 1,2,4,6,7,8: The original diameter of full cone type (d = 7.5 mm) is enlarged become d = 10mm
- Modification 3,5,9,10: The original diameter is enlarged become d = 10mm, but there is eccentric defect

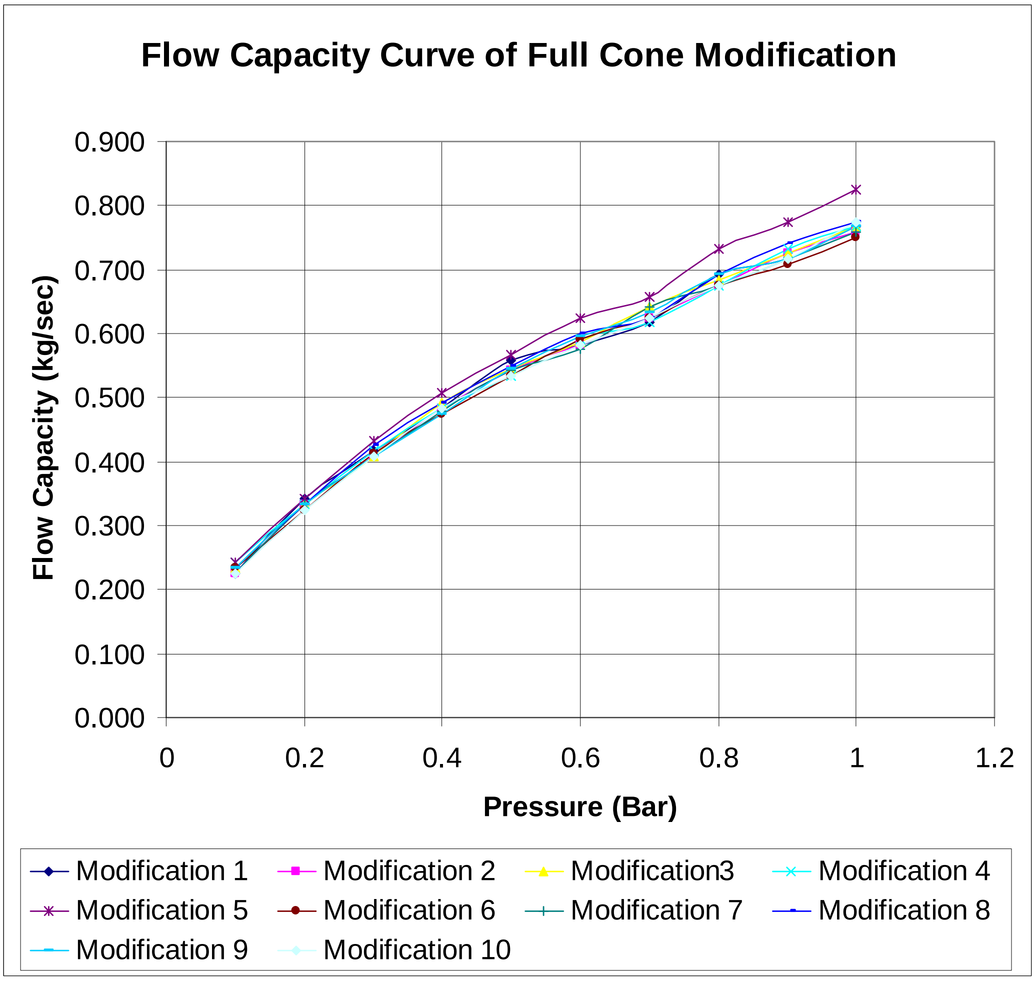


FIGURE 3.

Full Cone Type Original	Full Cone Type Modification

FIGURE 4.

TABLE - 4

Description	Unit	Design	29 May 2000	09 Jun 2003	23 Jun 2004	09 Dec 2004	Proposed
Total Measured Flow	kg/s	5,062	4,873	4,563	4,535	4,185	5,526
Estimated Auxiliary Flow	kg/s	423	423	423	423	423	423
Calculated Condenser Flow	kg/s	4,639	4,450	4,140	4,112	3,762	5,103
Design Flow	kg/s	4,639	4,639	4,639	4,639	4,639	4,639
Flow Margin	%	0%	-4%	-11%	-11%	-19%	10%
Turbine Output	MW	110	110	110	113	111	114
Steam Flow	kg/s	204	209	208	213	213	213
Condenser Press	Bara	0.12	0.104	0.108	0.113	0.138	0.11
CW Inlet Temp	Dec C	23.5	24.3	23.9	24.4	25.5	24.3
CW Outlet Temp	Dec C	44.8	44.5	44.9	45.7	49.2	44.5
Temperature Difference	Dec C	21.3	20.2	21	21.3	23.7	20.2
Actual Heat Load	kg/s.C	107821	98435	95823	96596	99185	111458
Design Heat Load	kg/s.C	107821	107821	107821	107821	107821	107821
Ratio Actual/Design		1.00	0.91	0.89	0.90	0.92	1.03

Revision:

	Tinlet	h (kJ/kg)	T outlet	h (kJ/kg)	m (kg/s)	Q (KW)	Q ideal (kJ/h)	Ratio
Design	23.5	98.496	44.8	187.51	4,639	412,936	412,936	1.00
29-May-00	24.3	101.84	44.5	186.26	4,450	375,669	412,936	0.91
09-Jun-03	23.9	100.17	44.9	187.93	4,140	363,326	412,936	0.88
23-Jun-04	24.4	102.26	45.7	191.28	4,112	366,050	412,936	0.89
09-Dec-04	25.5	106.86	49.2	205.91	3,762	372,626	412,936	0.90
Proposed	**24.3**	**101.84**	**44.5**	**186.26**	**5,103**	**430,795**	**412,936**	**1.04**

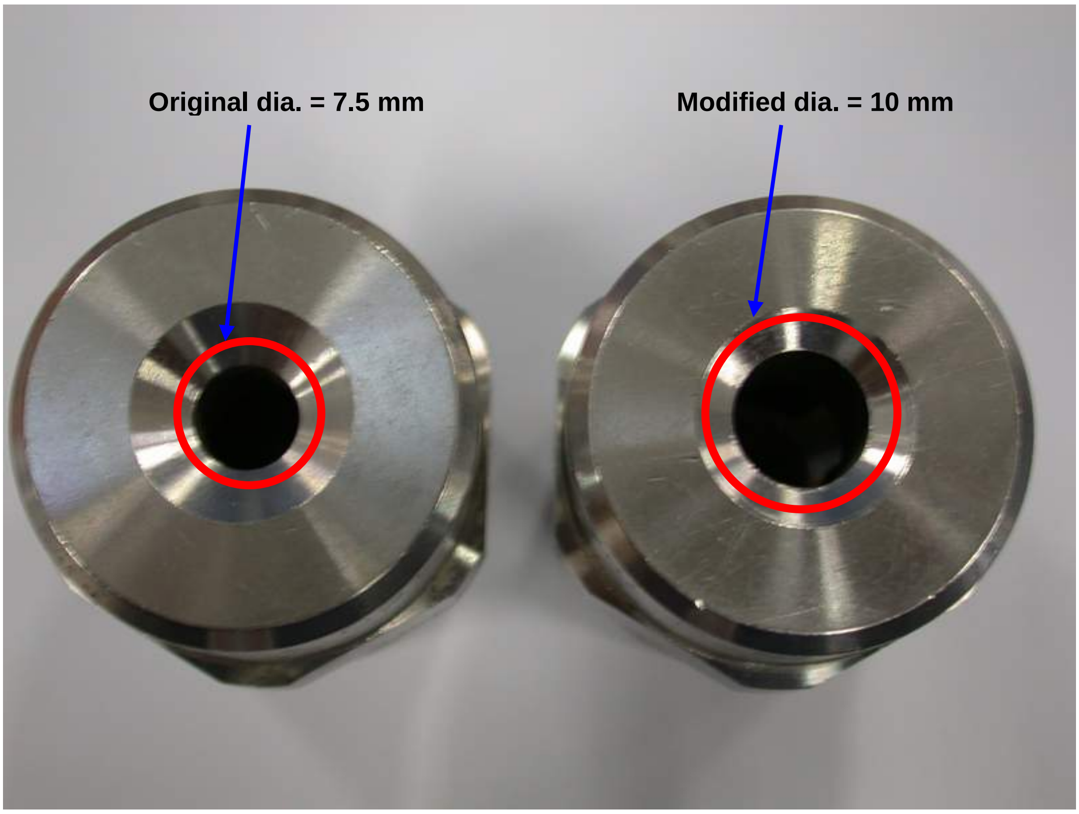


FIGURE 5: Original Nozzle and Modified Nozzle

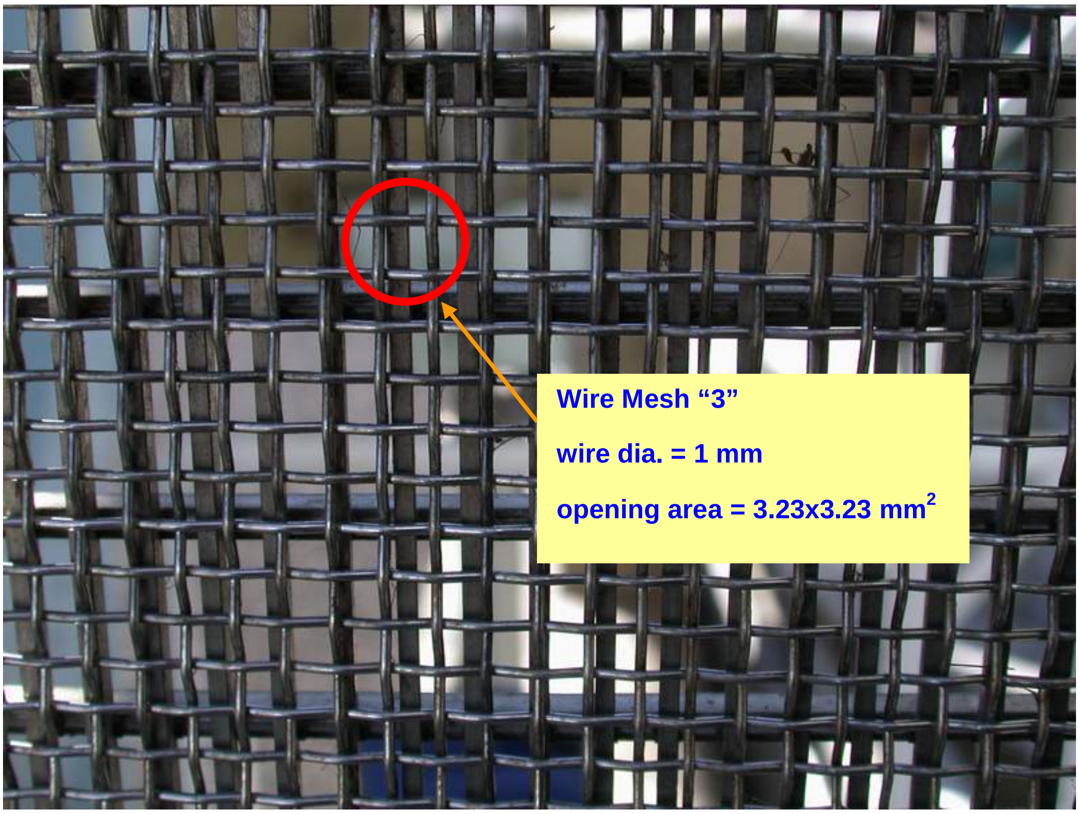


FIGURE 6: Fine Wire Mesh Installation at CT Exit Screen