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Hydraulic Pressure Testing Of Turbo Generators Radiators And Heat Exchangers For Effective Power Generation

Bernard Akindade Adaramola
Mechanical and Mechatronics Department, Afe Babalola University, P.M.B. 5454, Ado-Ekiti, Ekiti- State, Nigeria

Abstract

Hydraulic pressure testing is a proven technique of leak detection for monitoring the performance of radiators, heat exchangers, coolers, and condensers in turbomachinery. Radiator leak tightness test which is a dynamic gas micro-flow measurement to detect the existence of one or more leak flow paths or micro-channels was carried out on all the eleven radiators. Similar pressure testing was carried out for the entire six heat exchangers and the manometer reading was observed and the pressure was recorded at intervals of 10 minutes. Experimental investigation reveals pressure drops. This indicates that the radiator's tubes were weak and has punctured as they could not hold a pressure of 4 bars for the pressure testing period of 30 minutes. Maintenance was carried out on the radiators to eliminate leaks that cause the pressure drops. The pressure reading was monitored until all radiators and heat exchangers hold manometer pressure at 4 bars for about an hour. This significantly reduced overheating within the turbo generators for enhanced performance and increased availability.

Key Words: Heat Exchangers, Leak Detection, Manometer, Pressure Testing, Radiators.

1. Introduction

Evaluation of overall heat transfer coefficient, U at the field is a rigorous procedure for monitoring the heat exchanger performance as it entails step by step procedure for the evaluation of overall heat transfer coefficient as detailed monitoring and recording of steady-state parameters of the heat exchanger under consideration; a collection of test data of physical properties of the stream; and the calculation of thermal parameters of heat exchangers for comparison with design data lot of work. Technical records must contain heat transfer coefficient data versus time/ date of observation to identify the problems associated with heat transfer and efficiency reduction. A plot of heat transfer coefficient data versus time permits real-time planning of the heat exchanger cleaning program (Liberman & Norman, 1995). A lot of work has been done in computing the overall heat transfer coefficient, **U** and any deviation in experimental data from the design data indicates the occurrence of fouling. Bureau of Energy Efficiency experimented with 564 and further experimented with 574 for energy performance assessment of heat exchangers. If the operating heat duty is less than design heat duty, it may be due to heat losses, fouling in tubes, reduced flow rate (Kakac and Hongtan, 2002).

This work adopts a simple leak detection technique of hydraulic pressure testing of radiators and heat exchangers to enhance the performance of turbo generators for continuous availability for power supply as Lieber Kakac and Hongtan, 2002 experimented with a simple performance monitoring of exchanger where the efficiency may be considered a factor of performance irrespective of other parameters (Yu & Chan, 2005). Leak tightness is an emerging concern for many product designers, manufacturers, and users. There is great confusion in the definition and application of leak-tightness as a result of improper leak-tightness design specifications. A product leakage is typically a micro-flow phenomenon associated with difficulties in using the right tools for testing, correlating, and analyzing leak tightness during product manufacturing and quality control (Sagi, 2004).

There is a strong economic and environmental pressure to establish standards to reduce steam valve seal leakage in process industry valves. Consequently, users have applied pressure on industries to demonstrate practicable standards required to conduct valve qualification and quality assurance measurements economically that give sufficiently accurate and representation of in-service performance (Lieberman and Norman, 1995). The adaptation of the Equivalent Channel (EC) concept for leak tightness simplifies product technical specifications and product tightness correlations for industrial applications. The use of air micro-flow sensors and measurement actuators help to reduce cost; simplify the leak test process and ensure product seal integrity for meeting newer customer demands (Csillag, 2003).

The majority of fugitive emissions on petrochemical or chemical sites come from leaking valves. The European Sealing Association (ESA) focused much attention on this issue, intending to help valve manufacturers and users in reducing valve leakage. Consequently, the ESA commissioned a valve emission test program awarded a joint venture to two independent test institutes with the initial results reported at the Conference in Antwerp. The ESA is now collaborating with the valve industry and end-users on the second stage of this venture with support from the European Commission under the Standards Measurements and Testing (SMT) protocol as project SMT4-CT97-2158 (Lieberman and Norman, 1995).

A lot of experimental data acquired from a monitoring device for the leakage of cooling gas in the turbogenerator stator have been widely used in a dynamoelectric machine. The device is located next to the generator so that the operative elements are at the generator storage (Hargett, 2006). Hungarian Patent No. 192,380 and in paper A78307-1 IEEE, PES Winter Meeting, January 1998, investigated leak tightness for automatically venting the water-cooled system of turbo generator stator windings, and for providing a warning signal at a predetermined rate of gas penetration (Campbell et al, 1994). In April 1994, Grobel conducted a Leak detection system for liquid-cooled generators and researched into the arrangement for indicating leakage between cooling systems of turbo generators. Kudlacik in July 1997 worked on a liquid coolant pressurizing device for dynamoelectric machines and investigated the leak indicating apparatus for a closed cooling system of an electric machine. In 2001, Silverado carried out leakage measuring experiments for a gas-cooled, liquid-cooled, dynamoelectric machine to check the lines for fuel leak at the base of the turbo generator engine. In 2002, General Electric Company (Schenectady, NY) the United States conducted a field search on Hydrogen leak monitor for a turbine-generator (Csillag, 2003).

1.1 Radiators

The radiators are special heat exchange equipment, which transfers heat from one medium to another. Proper design, operation, and maintenance of heat exchangers will make the process energy efficient with minimal energy losses. Heat exchanger performance deteriorates with time, off-design operations, and other interferences such as fouling, scaling, etc. Periodical assessment of the heat exchanger performance is necessary for its effectiveness and to maintain a high-efficiency level (Sagi, 2004; Pipenger and Koff, 2005).

Shiroro hydropower turbo-generators have 11 numbers of radiators to cool the lubricating oil between the turbine shaft, the guide segment pads, and the thrust bearings. A high-pressure pump comes up to create oil film between the shaft load of weight 400tonnes (about 13 trailer load of cement) resting on the thrust bearing. The high-pressure pump cuts off automatically when the shaft rotation reaches 75 rpm. At the start and shut down the pump is on when the speed is below 75 rpm. Shaft rotation creates heat in the oil of about 40,000 liters (20 drums). To maintain oil properties particularly flashpoint, temperature monitoring sensors are attached to the radiators divided into two segments; the inlet side and the outlet side. Cool water enters the inlet side tubes and takes away heat from the oil surrounding the heat exchanger shell by convection. The hot water goes out through the tubes of the outlet side. Thus the cooling oil is cooled preventing flammability at high temperate developed when the generator is running at high speed (Blonch and Geitner, 2005).

1.2 Heat Exchangers

A heat exchanger is a piece of equipment that continually transfers heat from one medium to another to carry process energy. There are two main types of heat exchangers namely direct and indirect heat exchangers. Indirect heat exchangers both media between which heat is exchanged are in direct contact with each other such as cooling tower, where water is cooled through direct contact with air. For indirect heat exchangers, both media are not mixed but separated by a wall through which heat is transferred. Temperature losses through radiation can be disregarded when considering heat exchangers in turbo generators (Perry and Green, 2004).

Indirect heat exchangers are available in several main types: Plate; Shell and Tube; Spiral etc. In most cases the plate type is the most efficient heat exchanger because it offers the best solution to thermal problems, giving the widest pressure and temperature limits within the constraint of current equipment. The most notable advantages of a plate heat exchanger are thin material for the heat transfer surface that gives optimum heat transfer as the heat only has to penetrate thin material. High turbulence in the medium also gives higher convection which results in efficient heat transfer between the media. A smaller surface area requirement for a higher heat transfer coefficient per unit area makes the plant more efficient. The high turbulence also gives a self-cleaning effect compared to the traditional shell and tube heat exchanger. The fouling of the heat transfer surfaces is tremendously reduced which makes the plate heat exchanger remain in service far longer between cleaning intervals. The majority of plate heat exchangers manufactured by Alfa Laval are available with two different pressing patterns and easy to open for cleaning, the higher pressure drop with more effectiveness (Kakaç and Hongtan, 2002).

The Shiroro hydropower turbo-generators use 6 numbers of shells and tube heat exchanger for oil cooler with oil at the shell side and cooling water at the tube side. This class of heat exchanger designs finds higher-pressure applications in oil refineries and other large chemical processes. This type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes while the other fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of tubes composed of several types of tubes bundles: plain, longitudinally finned, etc. There are different designs variation on the shell and tube as the ends of each tube are connected to plenums (sometimes called water boxes) through holes in tube sheets. These tubes can be designed to be straight or bent in the shape of a U, called U-tubes. (Wilson, 1988; Kakaç and Hongtan, 2002).

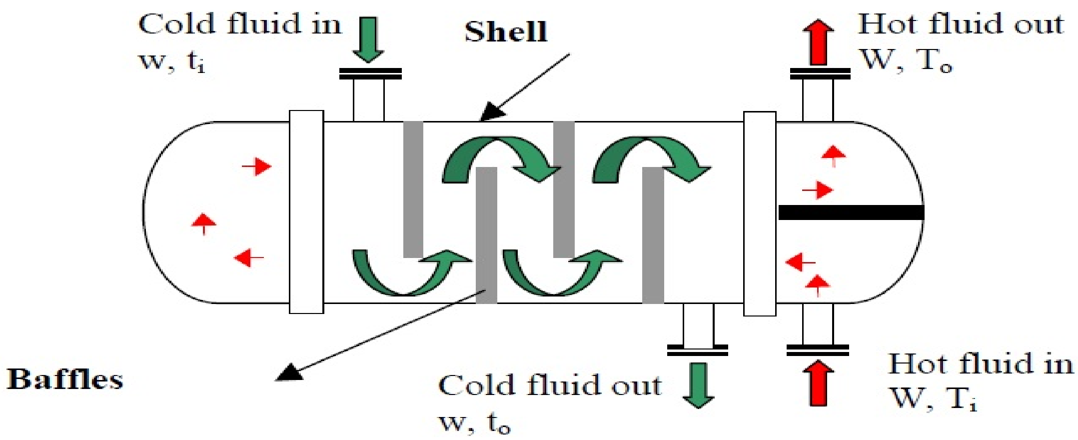

Figure1: Typical Turbo Generator Shell and Tube Heat Exchanger.

Nuclear power plants use pressurized water reactors (steam generators) which are large two-phase shell-and-tube heat exchangers with U-tubes. They are used to boil water recycled from a surface condenser into steam to drive a turbine to produce power. Most shell-and-tube heat exchangers are 1, 2, or 4 pass designs on the tube side. Pass design refers to the number of times the fluid in the tubes passes through the fluid in the shell. In a single pass heat exchanger, cold fluid enters at one end of each tube, and hot fluid exit at the other end. Baffles direct flow through the shell side and ensure the fluid do not leave the shell side through a short cut to cause effective low flow volumes. Countercurrent heat exchangers are most efficient because they offer the highest log mean temperature difference between the hot and cold streams. In industrial practice, multiple heat exchangers are employed to simulate the counter-current flow of a single large exchanger (Kakaç and Hongtan, 2002).

2. Material and Methods

The materials and apparatus used for radiator leak tightness test and heat exchanger pressure testing includes Manometer (device measuring pressure up to10 bar); High-pressure washing machine; M6 Porker Brush; Air Compressor; Radiator trolley; Powerhouse overhead crane; Halogen lamp, Bucket of soap water; Special service toolbox containing a set of Allen keys, hammers, spanners and screw-drives; and Safety gadgets (overall, safety boot, hand gloves, and nose fume proctor gloves).

2.1 Experimental setup

The experimental procedure follows 10 analytical steps on a vertically oriented copper tube in the length of 1350 mm with 2.5 mm inner diameter and 1 mm wall thickness. Tubes are measured in a bundle of 67 tubes to eliminate small geometric imperfections of each tube. Also measured values in the bundle more correspond with the statistical average and edge effect are eliminated concurrently. The bundle of 67 tubes is surrounded by an outer copper tube of diameter 500 mm. The experimental setup shown in figure 2 describes the division between the loop of water steam and the loop of cooling water.

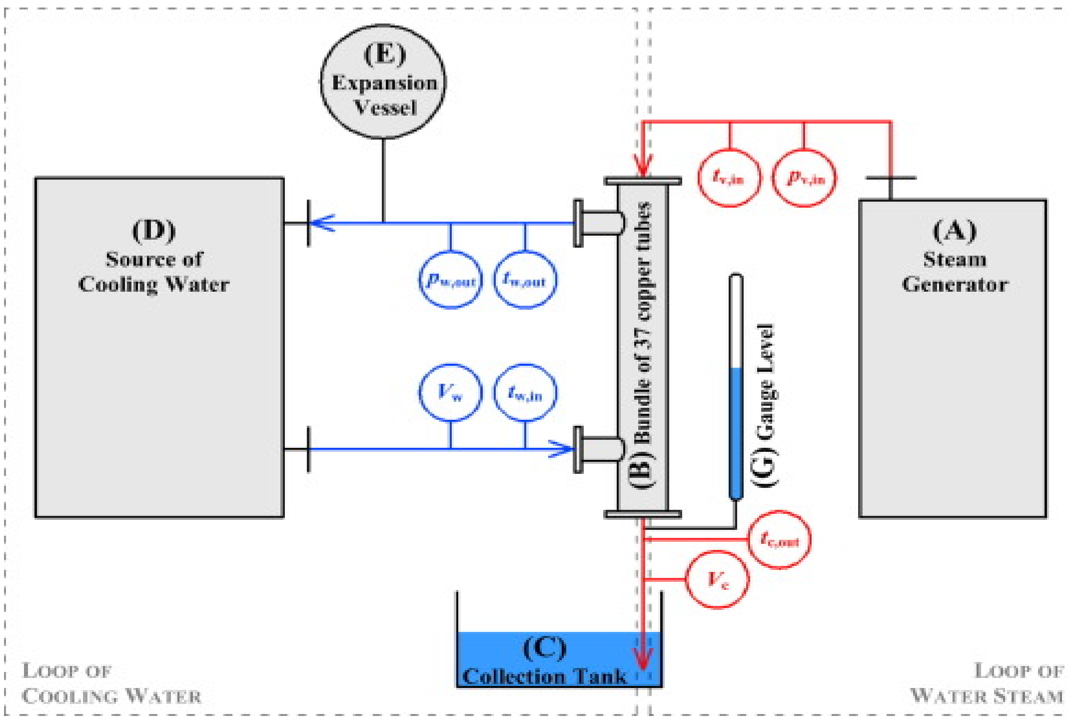

Figure 2. Scheme of the experimental setup.

The loop of water steam is composed of a steam generator (*A*), where water steam is produced at a temperature $t_{v,in}$[°C] and pressure $P_{v,in}$[Pa]. The water steam then enters into a measured bundle of 67 copper tubes (*B*), where the condensation process is achieved. The volume flow rate of condensate V_c [m^3/s] and temperature of the condensate $t_{c,\ out}$ [°C] is measured on the outflow from the bundle before the collection tank (*C*). The interspace of the bundle is counter-flow cooled by a loop from a source of cold water (*D*). Inlet temperature $t_{w,in}$ [°C] and volume flow rate V_w [m^3/s] of cooling water is monitored at the entering of the tube bundles. Outlet temperature $t_{w,out}$ [°C] and pressure $P_{w,out}$ [Pa] of cooling water is then measured on the outflow from the bundle of tubes. The volume changes of cooling water are compensated by the expansion vessel (*E*). The steam condensate level *H* [m] in the measuring tubes is displayed on an external gauge level (*G*).

The inlet temperature of water steam is changed in 10 steps for experimental measurement in the range from $t_{v,in}$ = 100 °C to $t_{v,in}$= 120°C. The mass flow rate of water steam is also changed concurrently in the range from m_v = 0.0090 kg/s to m_v = 0.01160 kg/s. The changed input parameters of water steam are kept constant for a sufficiently long period to achieve a thermal steady state, depending on the monitored values. Mass flow rate m_w = 0.275 ± 0.001 kg/s and inlet temperature $t_{w,in}$ = 11.0 ± 0.2 °C of cooling water is almost on constant value for the whole time, as shown in Table 1. The uncertainty of certificated gauges is on temperature sensor ±0.3%, pressure gauge ±0.6%, external gauge level ±0.2% and uncertainty of volume flow rate is ±0.5%. The internal surface of measured tubes is cleaned by a high percentage of alcohol cleaner until the water steam from the steam generator is 100 % pure.

2.2 Radiator Leak Tightness Test

Three 3" gate valves (inlet and outlet) to the radiators were disconnected for 11 numbers of radiators. Radiators were removed from the generating unit using the powerhouse crane and carried outside the powerhouse with a radiator trolley. Radiator top and bottom covers were opened on the trolley. Muddy particles and LX 188 hydraulic filter debris were forked (pushed) out of the radiator tubes using M6 Porker brush. Radiator tubes were flushed and washed with foaming water from a high-pressure washing machine. Top and bottom covers were coupled back to the radiator with new gaskets installed. The 3" gate flange at the inlet to the radiator was blocked with a blind blocker. A 10 bar pressure measuring manometer was connected to the outlet of the radiator. The radiator tubes were first fed with water at the bleeding ½" ball valve until the manometer pressure reading reaches 2 bars. As the pressure reaches 2 bars, the radiator was charged with compressed air until the manometer reads 4 bars. The pressure reading was monitored with the manometer pressure at 4 bars for about an hour. Manometer reading was observed and the pressure was recorded at intervals of 10minutes. The above procedure shown in figure 3 was carried out for the entire 11 radiators.

Figure 3: Radiator Pressure Test Experimental Setup (at Shiroro Power Station)

2.3 Heat Exchanger Pressure Testing

The 3" gate valves (inlet and outlet) to the heat exchangers were dismantled. The drain ½" gate valve was kept in a close position. The 3" gate flange at the inlet to the heat exchanger was blocked with a blind blocker. A 10 bar pressure measuring manometer was connected to the outlet of the heat exchanger. At the bleeding ½" ball the air compressor hose was connected to the top of the heat exchanger. The heat exchanger was charged with compressed air until the manometer read 4 bars. Soap water was robbed at the bleeding ½" ball and manometer connections to detect any air leak. With the manometer pressure at 4 bars, the pressure reading was monitored for 30 minutes. Manometer reading was observed and the pressure was recorded at intervals of 10minutes for all the 6 heat exchangers as depicted in figure 4.

Figure 4: Heat Exchanger Pressure Testing Experimental Setup

3. Results and Discussion

The results of experimental values measured in 10 steps is presented in table 1.

Table 1: Heat Exchanger Experimental Measured Parameters.

					PARAMETERS OF STEAM WATER				PARAMETERS OF COOLING WATER		
S/N	**Q_v [kW]**	**q_v [kW/m^2]**	**k [W/(m K)]**	**H [m]**	**m_v [kg/s]**	**$P_{v,in}$ [kPa]**	**$t_{v,in}$ [°C]**	**$t_{c,out}$ [°C]**	**m_w [kg/s]**	**$t_{w,in}$ [°C]**	**$t_{w,out}$ [°C]**
1	20.28	74.442	9.346	0.392	0.009	101.6	100.0	35.0	0.275	10.9	30.8
2	20.45	78.381	9.425	0.417	0.011	122.5	112.3	34.6	0.276	10.8	31.2
3	21.35	80.334	9.486	0.435	0.012	142.7	113.5	35.4	0.274	10.9	31.8
4	2172	73.346	9.335	0.336	0.013	118.6	112.0	46.0	0.275	11.2	32.3
5	22.84	81.235	9.483	0.373	0.014	177.6	116.5	47.8	0.285	11.1	32.5
6	23.23	81.313	9.483	0.365	0.015	180.5	117.0	47.8	0.283	11.1	35.3
7	24.78	78.452	9.429	0.315	0.016	161.6	113.6	50.1	0.283	11.2	34.2
8	25.53	71.983	9.270	0.198	0.017	113.2	103.1	50.9	0.284	11.1	35.3
9	25.86	74.575	9.349	0.226	0.018	141.5	109.6	39.4	0.283	10.8	35.9
10	26.27	72.854	9.353	0.199	0.019	133.5	112.3	39.9	0.284	10.9	36.2
$U_{\%}$	±1.1%	±1.1%	±1.7%	±0.2%	±0.5%	±0.6%	±0.3%	±0.3%	±0.5%	±0.3%	±0.3%

The transferred condensation heat Q_v [W] between water steam and cooling water is computed from equation: $Q_v = m_v(h_{v,in} - h_{c,out})$, where specific enthalpy of water steam condensate is $h_{c,out}$ = 419.10 kJ/kg and condensation temperature is $t_{v,out}$ = 100 °C. The logarithmic mean temperature difference ΔT [K] for counter-flow involvement is determined from Eq. $\Delta T = (t_{v,in}-t_{v,out})/(t_{w,out}-t_{w,in})$. The one-dimensional state steady overall heat transfer coefficient k [W/(m K)] for the cylindrical wall in the condensing zone is calculated from Eq. $U = (Q_v)/(A\ \Delta T)$. Heat exchanger Effectiveness, $S = (t_{w,out}-t_{w,in})/(t_{v,in}-t_{v,out})$. Finally, the condensation heat transfer coefficient α_v [W/(m^2 K)] is determined by the Thermal resistance method and Wilson plot method

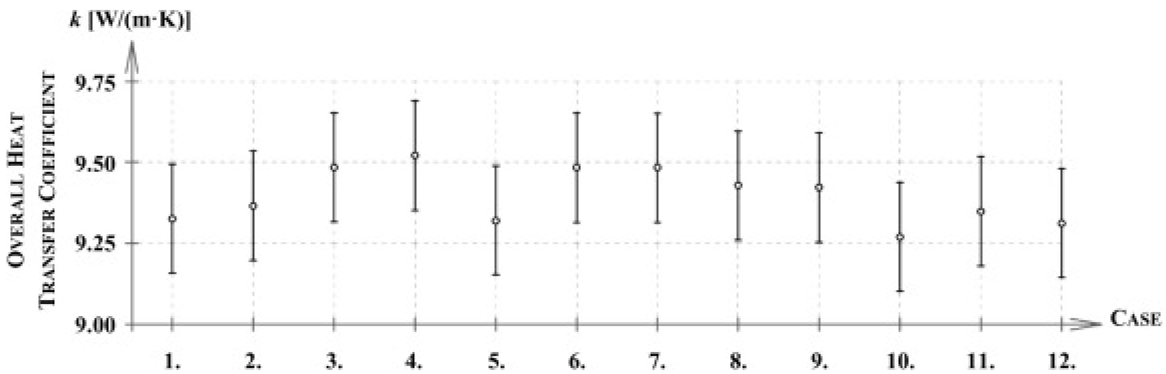

Figure 2. Overall heat transfer coefficient k [W/m K] determined from experimental measurement

3.2 Radiator Leak Tightness Test

The result of pressure testing carried out to detect leakage in the Unit 411 G 3 eleven radiators is presented in tables 2.

Table 2: Unit 411 G 3 *Result* of Pressure Testing of Radiators

TIME Minutes	RADIATOR PRESSURE (Bars)										
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
10	4.0	3.9	4.0	3.90	4.0	4.0	4.0	4.0	4.0	3.90	4.0
20	4.0	3.8	4.0	3.85	4.0	4.0	4.0	4.0	4.0	3.85	4.0
30	4.0	3.7	4.0	3.75	4.0	4.0	4.0	4.0	4.0	3.70	4.0

Leak tightness testing is a dynamic gas micro-flow measurement to detect the existence of one or more leak flow path or micro-channels. In Table 2 pressure drop was observed in Unit 411G3 radiators numbers 2, 4, and 10 which indicate the tubes in these radiators were weak and has punctured as they could not hold a pressure of 4 bars for the pressure testing period of 30 minutes. The pressure drop is clearly shown in the bar chart presented in figure 3 for radiators numbers 2, 4, and 10. At steady-state conditions, the mass flow into the control volume is supposed to be equal to the mass flow leaking from it. The measure of the make-up flow to hold constant pressure is the leak flow rate.

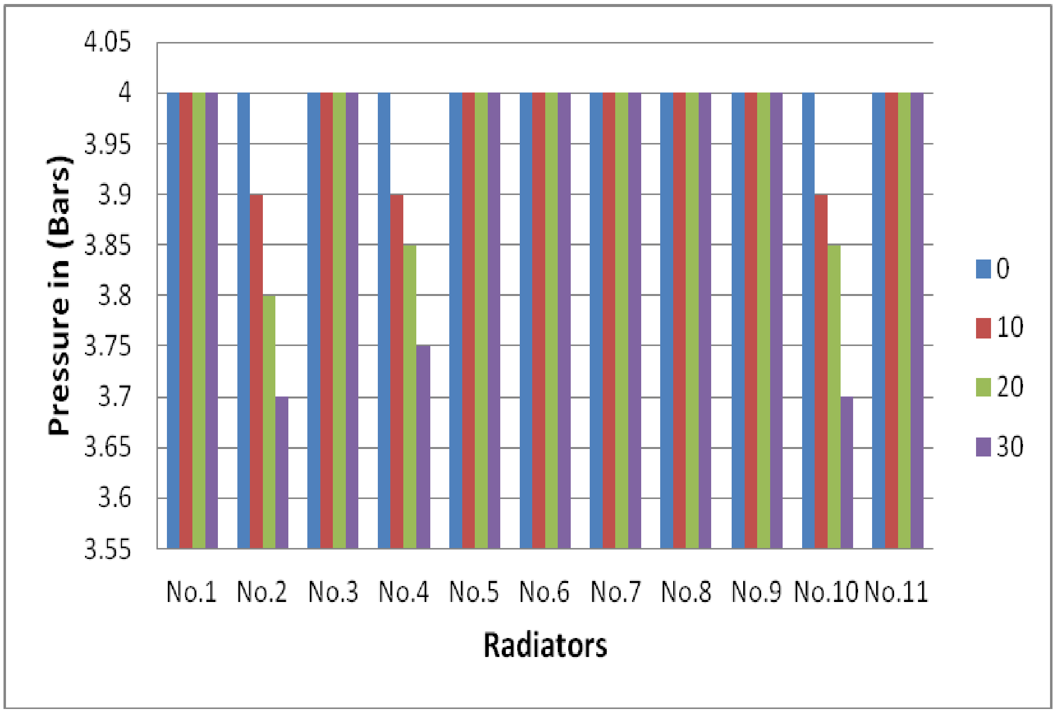

Figure 3: Result of Pressure Testing of Radiators.

It is important to ensure that no tube is punctured to prevent water from entering directly into the stator windings. Leakage is typically a micro-flow phenomenon that posts challenges of fugitive emission due to difficulties in applying correct tools for testing, correlating, and analyzing leak tightness during power generation. Radiator design allows one third (67 of 201 tubes) of weak tubes to be blocked. Punctured tubes of radiator No. 2, 4, and 10 were blocked with tarpon material at the upper and lower end and pressure testing was carried out again and the result presented in Table 3.

Table 3: Unit 411 G.3 Result of Pressure Testing of Radiators after Maintenance

TIME Minutes	RADIATOR PRESSURE (Bars)										
	No.1	**No.2**	**No.3**	**No.4**	**No.5**	**No.6**	**No.7**	**No.8**	**No.9**	**No.10**	**No.11**
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
10	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
20	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
30	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0

The final result of pressure testing of radiators after maintenance presented in table 3 shows that all the 11 radiators held the pressure of 4 bars for the test period of 30 minutes. This shows that none of the radiator tubes was punctured or leaking ensuring valve seal integrity.

3.3 Heat Exchangers Pressure Testing

The result of the pressure testing experiment carried out on Unit 411G 3 six heat exchangers is presented in table 4: below:

Table 4: Unit 411 G-3 Result of Pressure Testing of Heat Exchangers

TIME Minutes	HEAT EXCHANGERS Pressure (Bars)					
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
0	4.0	4.0	4.0	4.0	4.0	4.0
10	4.0	3.90	4.0	4.0	4.0	4.0
20	3.90.	3.90	4.0	4.0	4.0	3.90
30	3.87	3.85	4.0	4.0	4.0	3.82

Pressure drop experienced in heat exchangers 1, 2, and 6 as shown in Table 4.6 indicate two problems; either one or more tubes punctured or weak O- ring seals at the top of heat exchangers between the shell and the bearings. Data from table 3 employed to draw a bar chart in figure 4 which clearly shows the pressure drop in heat exchangers 1, 2, and 6.

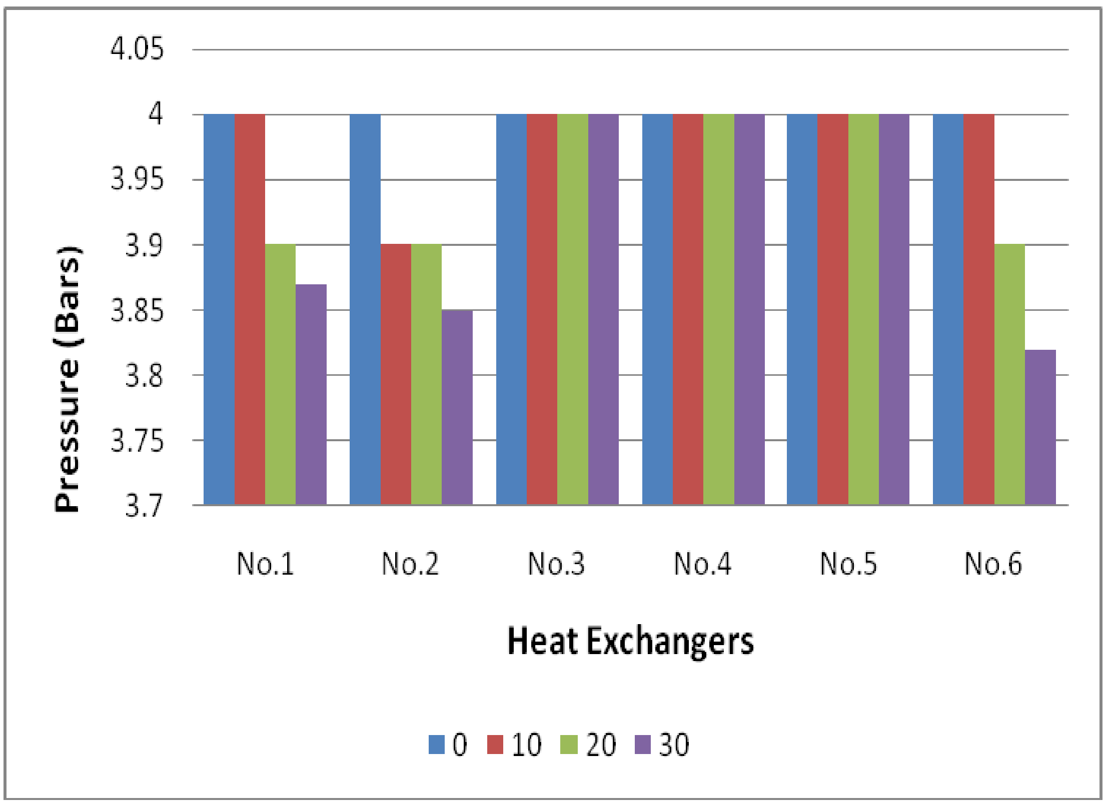

Figure 4 Pressures Testing of Heat Exchangers

Weak O- rings causes water to mix with the oil. When No.1, 2, and 6 Heat exchanger's upper and lower covers were removed for inspection the O- ring seals some tubes were found to be weak causing oil drop (leakage).

Table 4 below presents the result of final pressure testing of the six heat exchangers after weak and leaking tubes were replaced.

Table 4: Unit 411 G3 Result of Pressure Testing of Heat Exchangers after Maintenance

TIME Minutes	HEAT EXCHANGERS Pressure (Bars)					
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
0	4.0	4.0	4.0	4.0	4.0	4.0
10	4.0	4.0	4.0	4.0	4.0	4.0
20	4.0	4.0	4.0	4.0	4.0	4.0
30	4.0	4.0	4.0	4.0	4.0	4.0

All the heat exchangers held a test pressure of 4 bars for 30minutes. This implies that the tubes were no more punctured or leaking. This means that after maintenance and repairs which involve the replacement of punctured tubes the heat exchangers are functioning well.

4. Conclusions

Leakage is typically a micro-flow phenomenon that posts challenges of fugitive emission due to difficulties in applying correct tools for testing, correlating, and analyzing leak tightness during power generation. It is important to ensure that no tube is punctured to prevent water from entering directly into the stator windings. Pressure drop experienced in radiators and heat exchangers indicates two problems; either one or more tubes punctured or weak O- ring seals at the top of heat exchangers between the shell and the bearings. Weak O- rings causes water to mix with the oil. Leak tightness is an ongoing concern for many product designers, manufacturers, and users. It is imperative to eliminate the confusion that arises as a result of improper leak-tightness design specifications. A product leakage is typically a micro-flow phenomenon associated with difficulties in using the right tools for testing, correlating, and analyzing leak tightness during product manufacturing and quality control. Proper maintenance ensures radiator and heat exchangers tubes were no more punctured or leaking ensuring valve seal integrity. Hydraulic pressure testing is a sure technique for reducing overheating within the turbo for continuous availability for power generation.

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