International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

Designing of Energy Efficient Rotary Steam Coil Air Pre-Heater (SCAPH) for Fossil Fueled Thermal Power Plant

Sunil Kumar Gupta
Head, Operation and Efficiency Department
Sasan Power Limited, Reliance Power
Singrauli, India

Arijit Debroy
Senior Manager, Efficiency Department
Sasan Power Limited, Reliance Power
Singrauli, India

Abstract: **Steam coil air preheaters (SCAPH) are found in most fossil-fueled utility and large industrial power plants. Their primary function is to pre-heat combustion air before it enters rotary regenerative air preheater or recuperative type air preheater. SCAPH provides corrosion protection for the air pre heater and maintains its cold end average temperature above acid dew point temperature during cold stringent weather condition. Most units use vertical, fixed finned tube coils embedded in the ductwork connection of the discharge side of combustion air source, Forced Draft fans, and the cold end inlet of Air Pre-Heater. This equipment can also have an additional purpose of preheating the combustion air during unit start-up by increasing the ambient air temperature up to a desirable temperature to reduce fuel oil consumption, thus aiding operators to take pulverizer into service early. Along with the advantages of this static bulky heat exchanger there lays a hidden disadvantage which impacts the auxiliary power consumption during normal unit operation at normal ambient conditions. As it is present in the discharge of forced draft fan a considerable amount of pressure drop occurs across the coils which leads to an increase of forced draft fan loading thus leading to an increase in auxiliary power consumption even in normal weather conditions. Without hampering the normal functionality of the SCAPH system an innovative approach has been taken and described in this paper through redesigning of a Static SCAPH system into a Rotary SCAPH system.**

Keywords: Steam coil air preheater, air preheater, rotary equipment, auxiliary power, retrofit, innovation, modification, energy efficiency, SCAPH

I. INTRODUCTION

Heating and cooling systems technology is one of the most important areas of mechanical engineering. Wherever heating and cooling of fluids is incorporated in a system we will find a heat exchanger. Heat exchangers have wide industrial applications and it is practically inexhaustible. In our basic study of heat transfer equipment in modern power stations, we often come across the term Steam coil air pre-heater (SCAPH) which is a heat exchanger used to heat atmospheric air to the required process temperature by means of superheated steam in thermal power industry. Steam flow inside the tube while air passes over the finned tubes. It is generally used for heating process air or combustion air. SCAPH has extensive uses in all High Capacity Boilers and Recovery Boilers. Steam coil preheater is used to heat inlet air to air preheater type (APH) in order to raise the cold end temperature thus preventing acid dew point corrosion. This type of equipment is normally incorporated into design of a boiler unit for low load operation and it can be used during unit start-up operation also. It has finned tubes which increases heat exchange surface area. It is generally located in the duct between the forced draft fan and the air pre-heater. Figure 1 and Figure 2 shows the arrangement of the fins in the tubes of SCAPH.

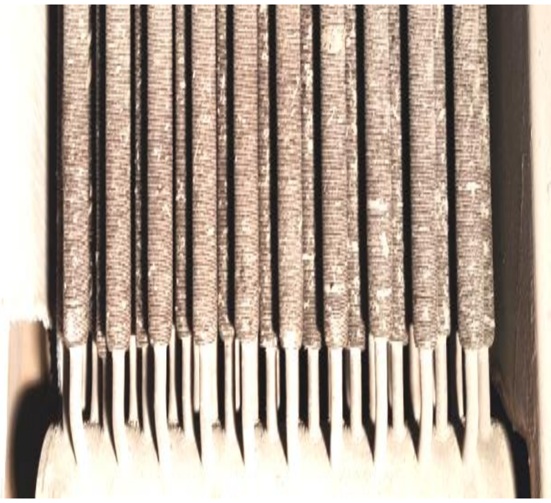

Figure 1: Finned tubes of SCAPH

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

Figure 2: Close view of the fins

II. INTRODUCTION TO AIR PRE-HEATER (APH) AND DISCUSSION ON COLD-END CORROSION

Air pre-heater is a heat recovery equipment, which improves the efficiency of boiler and also reduces the fuel consumption to extent of nearly 5 percent depending on duty. Figure 3 shows the rotary regenerative air pre heater and its major components and flow path of air and flue gas through it. In Air pre-heater the combustion air is preheated before admitting the air to combustion zone or furnace. The air preheating can be heated up to 300°C depending on type of combustion equipment. Since the heat is extracted from flue gas, the temperature of the flue gas can fall below the acid dew point temperature which generally ranges between 90°C to 110°C for Indian coals. As the ambient temperature falls down there is possibility that overall bulk mean temperature of the gas may fall below 110°C. SO_3 and H_2O present in the flue gas start to reacts with each other at such a lower temperature. Figure 4 shows the values of sulphuric acid dew points as a function of sulphite content in the flue gas and moisture. To increase the efficiency of the boiler SCAPH is introduced before air pre-heater. In SCAPH the low temperature ambient air is heated by low pressure steam to avoid cold-end corrosion. Apart from that pre heating combustion air by usage of SCAPH during unit light up aids in reduction of fuel oil consumption by enabling operators to take pulverisers early.

But during normal ambient temperature conditions and full load operation of thermal units SCAPH loses its usefulness and becomes a bulky burden as an auxiliary. This system imposes a resistance on the forced draft fans by the constant pressure drop across it. In this technical paper we will discuss the methodology of converting the static auxiliary into a dynamic rotary equipment through which we can reduce the resistance in the flow path of combustion air thus extracting benefit from the SCAPH system even during normal ambient conditions and full load unit operation.

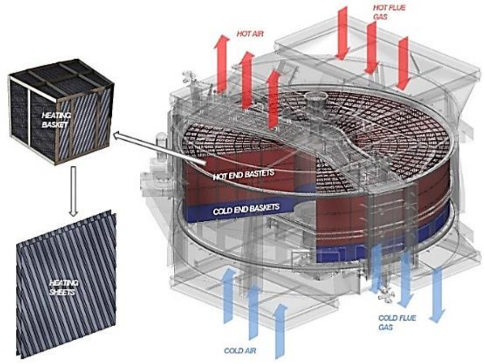

Figure 3: Regenerative Rotary Air Pre-heater [1]

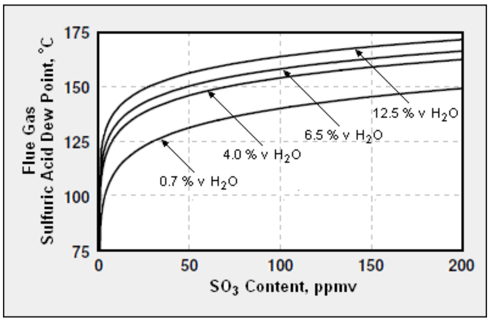

Figure 4: Calculated sulfuric acid dew points of typical combustion flue gases, as a function of SO_3 content, and water vapor content [2]

III. INTRODUCTION TO THE IMPLEMENTATION SITE

The retrofitting of the SCAPH system and implementation has been carried out in Sasan Ultra Mega Power Plant (SUMPP) which is a subsidiary of Reliance Anil Dhirubhai Ambani group located in Singrauli district of Madhya Pradesh. The plant capacity is 3960 MW (6 X 660 MW) based on Super Critical Technology having the best in class efficiency. It provides power at most competitive tariff in the country to 14 DISCOMs in 7 states. Sasan Power Limited (SPL) also has a mining production capacity of nearly 20 million metric ton per annum (MTPA) which is made possible by the “State of Art” mining equipment and Largest Size of Heavy Earth Moving Machinery (HEMM).

SPL is one of the largest integrated thermal power plant with captive coal mines at single location. SPL is operating at full capacity on continuous basis since commissioning, setting & raising

benchmarks for the power industry every day. The plant has achieved numerous awards & accolades in all areas of operations and efficiency. On the path of inclusive growth, it is making a positive impact on the life of surrounding community by way of education, healthcare, and training for skill development.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

- Design Meteorological Details: The elevation of power plant is 275 to 320 meter above sea level with design ambient temperature (dry-bulb temperature) of 32 °C and the extreme atmospheric temperature ranges between maximum of 42°C, minimum 8.1 °C.
- Boiler: The Boiler at SPL is a supercritical, variable-pressure operation, spiral tube once-through, single furnace, single reheat, tangential firing, balanced draft, semi outdoor arrangement, two-pass type manufactured by Shanghai Boiler Works Co. Ltd.

Table 1: Boiler, Turbine and Forced Draft Fan Performance Data at Design Coal

BOILER DESIGN PARAMETERS		
PARTICULARS	UOM	TMCR CONDITIONS
Calculated thermal efficiency of Boiler	%	87.34
Coal consumption	TPH	344.3
Excess Air at Furnace outlet		1.2
Gas Temperature Inlet of APH	°C	352
Primary Air Temperature leaving Primary Air Fan	°C	42
Secondary Temperature leaving Forced Draft Fan	°C	36
Primary Air Temperature at outlet of APH	°C	321
Secondary Air Temperature at outlet of APH	°C	327
Boiler Exhaust Gas temperature	°C	141
TURBINE DESIGN PARAMETERS		
Load	MW	660
Main Steam Pressure	MPa	24.2
Main Steam Temperature	°C	566
Main Steam/ Reheat Steam Flow	TPH	1975.8 / 1658
Reheat Steam Inlet and Outlet Pressure	MPa	4.65 / 4.21
Reheat Steam Inlet and Outlet Temperature	°C	321.9 / 566
Running Speed	RPM	3000
Cooling Water Inlet and Outlet Temperature	°C	32 / 42
Feed Water Inlet Temperature	°C	280.9
FD FAN DETAILED PARAMETERS		
Capacity of FD Fan at Design Coal and 100% BMCR	m^3/s	284.4
Motor Output	kW	1850
Total Pressure above Atmospheric Pressure (97770 Pa)	Pa	3479
Efficiency	%	85.79

- Turbine: The turbine model in SPL is N660 – 24.2/566/566 which is a super-Critical, Tandem Compound, Combined High Pressure (HP) and Intermediate Pressure (IP), 2 Low Pressure (LP) Turbine Double Flow, Intermediate Reheat, Condensing Type Turbine manufactured by Shanghai Electric Power Generation Equipment Co. Ltd.
- Table – 1 shows the details of the forced draft fan operating parameters installed at SPL and manufactured by Shanghai Boiler Works Co. Ltd.
  - Internal diameter of the fan 2818 mm
  - Diameter of the impeller hub 1412 mm
  - Stage number – One
  - Number of blades per stage 16
  - Blade material HF-1
  - Screwed connection between the blade and blade shaft
  - Impeller adjustment range -30°~+20°

- SCAPH design parameters and operational usage details — SCAPH (Steam Coil Air Pre-Heater) is equipment fitted between forced draft fans and air pre-heater to avoid the acid dew point condensation which occurs at the flue gas side in the air pre-heater due to the low temperature of the atmospheric air as stated earlier in the paper. The design parameters of SCAPH at SPL are as follows:
  - Number of SCAPH Assembly: 02
  - Number of coils in one assembly: 04
  - Number of Tubes: 42 in one coil
  - Inlet Header size: 150 mm
  - Outlet Header Size: 50 mm
  - SCAPH weight: 1.2 MT

(a) Material of construction: Tubes and other associated systems are made up of carbon steel having thermal conductivity around 45 to 50 watt per meter kelvin, SA210 grade.

(b) Operational details of SCAPH system: The operating pressure of the steam is taken nearly 8 to 12 bar (depending upon the steam pressure available in Auxiliary PRDS (pressure reducing de-superheating steam) station and temperature is taken with a minimal amount of superheat from saturation temperature at that corresponding pressure. forced draft fan deliver the air at ambient temperature and at

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

pressure of 150-220 mmwc (millimeter of water column) draft pressure. Generally, 20 to 25 mmwc pressure drop occurs in the SCAPH due to its complex geometry. SCAPH is taken into service when ambient temperature falls and reduces the flue gas outlet temperature of APH. SCAPH is also taken into service during unit start up and low load operation. Generally, in unit start up till synchronization oil guns are kept in service but due to various changes in material composition of boiler and change in operational philosophy now-a-days mill is taken in service prior unit synchronization. But there are some pre-requisites that are to be followed prior taking pulverizer in service. One such condition is that the secondary air or combustion air temperature at APH outlet should be greater than 160°C. Now, since ambient air temperature at 30°C passing through APH and gathering heat from the low temperature flue gas at unit startup will require more time to get heated up to 160°C, by using SCAPH the same activity becomes less time taking. With the initiation of SCAPH charging process we try to preheat the combustion air temperature from ambient temperature to at least 60-65°C prior sending it to APH for heat gain. This in turn reduces oil consumption. After unit synchronization the steam source to SCAPH is isolated.

(c) SCAPH system arrangement: Figure 5 shows the single line diagram of the SCAPH system arrangement at SPL prior modification.

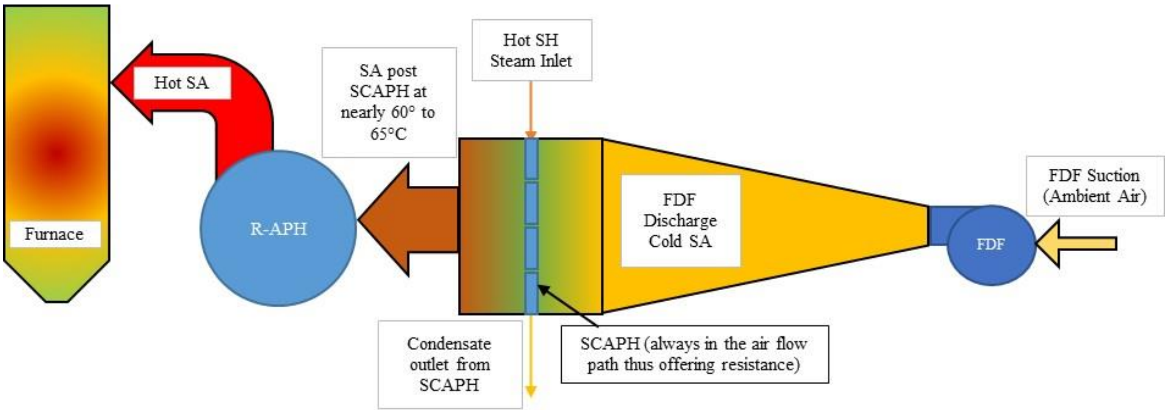

Figure 5: SLD of SCAPH System at SPL prior modification

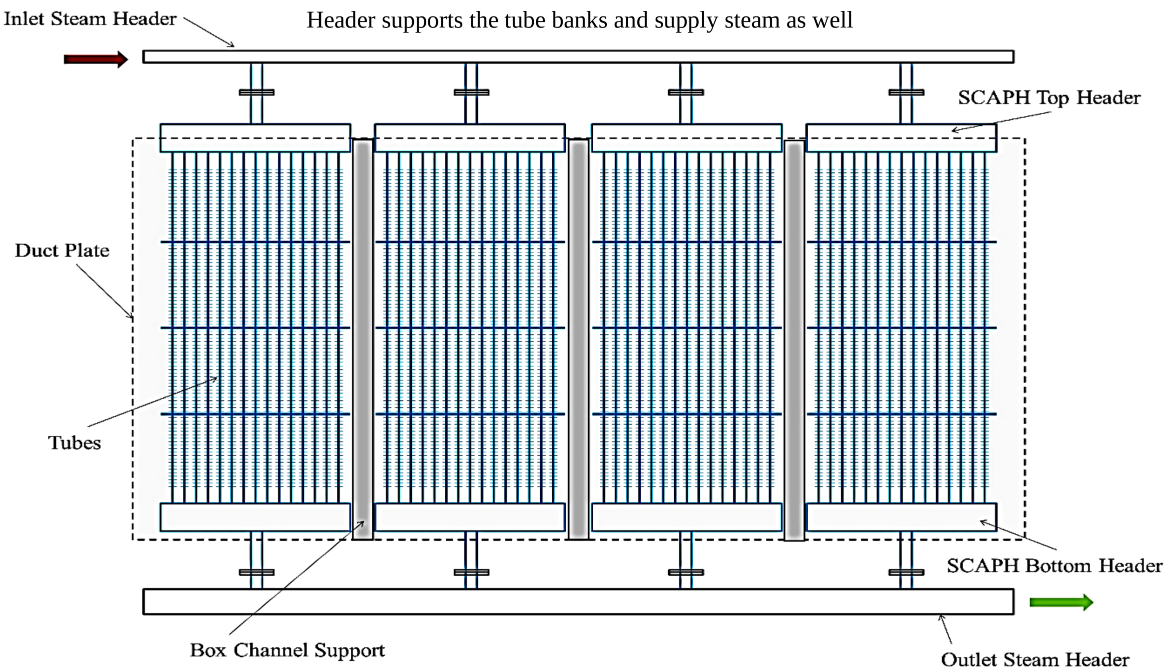

Figure 6: SCAPH prior modification

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

A. Concept of The Modification & Planning

There were many ideas which were pondered over to reduce auxiliary power consumption associated with the SCAPH system. Firstly we thought of eliminating the SCAPH permanently from the system but it would have left no option to help during times of cold end corrosion prevention. The second idea was to make an investment on erecting a bypass duct with additional path for air to the SCAPH system and to erect additional dampers for isolation during non-usage period. But it would be bulky and would require space. Lastly it was decided to turn the static SCAPH into a rotary SCAPH so that when not in use it remains parallel to the air flow path without causing any restriction in air path and thus the system resistance will automatically get eliminated without sacrificing the benefits of SCAPH to prevent cold end corrosion during peak winters or start-ups. In order to rotate such a bulky static system we have to first check for the points which upholds the weight of the tube banks which as shown in Figure 6 was the steam carrying inlet header. It acted both as the source of steam supply as well as the support to the tube banks. So in order to rotate the tube banks supported by the inlet steam header we have to transfer the weight of the tube banks to another section or system, which in our case was a channel, which would be discussed later, and then provide the steam supply through a different path as shown in Figure 16. Based on this concept we chalked out the in-house methodology of erection and it was a challenge for us to carry on with this modification at the lowest possible cost. Static SCAPH was thus modified into a Rotary SCAPH, just like an operating butterfly valve, which can be rotated by 90° after unit achieves full load or when its requirement ceases. Man, machine and material were expedited and a step-by-step erection procedure has been explained in this paper.

B. Step by Step Procedure for Erection of a Rotary SCAPH

The procedure and methodology followed for the erection of the Rotary SCAPH are understated:

1. Removal and relocation of steam inlet header: It was required due to space constraint for erection of the structure and for hanging the coil banks of SCAPH. It was done in order to erect the structure for SCAPH with the help of channel of dimension 300 X 125 mm of length 4500 mm and of height 600 mm.

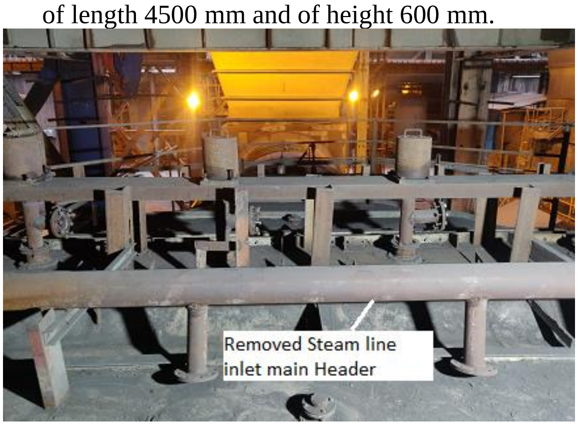

Figure 7: Steam Line Header

2. Erection of channel over the SCAPH frame for support of SCAPH coils: SCAPH is located at the discharge of forced draft fan duct and each forced draft fan consist of one SCAPH system and each SCAPH system consist of four coil banks and the total weight of all the four coil banks is 1190 kg. According to the load of coil, it was decided to use a channel of 300 x 125 mm.

   At the top of the 4200mm wide duct of forced draft fan a channel of length 4500 mm was taken and to support the channel from the side the same dimension channel was used of size 600 mm which was welded with the horizontal channel and at the side of the duct to provide proper strengthening of the channel.

Figure 8: Channel Erection

3. Fabrication & modification of forced draft fan outlet duct (within SCAPH frame): In the previous SCAPH system, the center of inlet header was welded with the top of the forced draft fan duct and minimum clearance was provided at outlet header discharge piping for thermal expansion of coils. The outer diameter of inlet header was 150 mm, so to rotate the SCAPH the duct height was to be increased from the center of the inlet header. The duct height was made to be 95 mm from the center of the inlet header. At the bottom of the duct, the discharge piping of outlet header the clearance was increased.

Figure 9: Modification of forced draft fan outlet duct

4. Pipe support provided from top to bottom frame of SCAPH instead of Box support:

   At previous condition there was a box channel which was provided (total 3 in numbers) for the support of the duct and locking of the coils but it created hindrance in rotation of the coil at the time of trial of

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

SCAPH rotation, so we replaced the box channel with the pipe support of diameter 141x10 mm and of length 6000 mm.

5. Arrangement of stuffing box for air side sealing at both end for steam inlet and outlet line in each bank of coil: As the system was converted from Static to Rotary, there must be some clearances that had to be provided for rotating the coil banks and to resist the air leakage from these clearances. We were bound to provide a proper air sealing system from inlet and outlet steam header of SCAPH.
At inlet and outlet header we provided a stuffing box, to eliminate the air leakages and for smooth rotation of the coil banks.

Figure 10: Outlet Header Stuffing Box

Figure 11: Inlet Header Stuffing Box

6. Extension & modification of steam inlet line length: After extension of top duct height, the inlet steam pipe line attached to the inlet header got short in length, so to provide the passage of steam to the inlet header, we provided a spool piece (which was welded with the inlet header steam line flange) of diameter 89 mm and of length 300 mm. In that spool piece at 90°, a steam pipe line with flange was provided which was then bolted with the main steam inlet header.

Figure 12: Spool Piece

Figure 13: Extension of steam inlet line length

7. SCAPH coil bank loading & rotating arrangement: The individual weight of coil bank is 298 kg which was acting vertically downward and the bearing should be capable to bear this axial loading. Therefore, thrust ball bearing was suitable for loading and rotating purpose. For loading of SCAPH coils, a hole of diameter of 110 mm was made in the channel to insert the shaft which was to be loaded on the thrust ball bearing along with bearing base plate which finally takes the load of coil with the help of tie rod (which was welded with the spool piece). Provision for alignment of SCAPH coils was also done and it was done with the help of adjusting nut screwed to the tie rod & base plate kept on the channel.

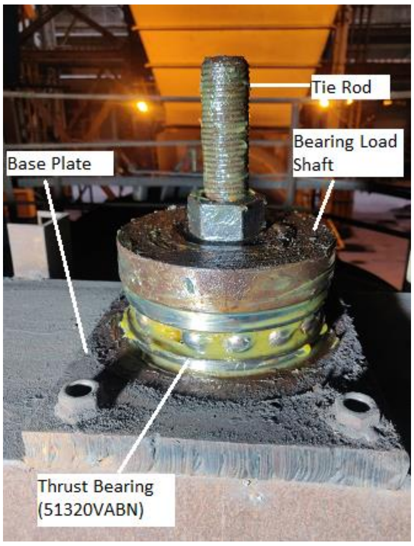

Figure 14: Thrust bearing with load shaft

8. Handle provision and Locking arrangement of SCAPH coil bank: For ease of rotation of SCAPH coils in operating condition, a handle was provided (for rotating SCAPH coil) which was welded with tie rod and to avoid reverse rotation of coils we have provided a locking system to lock the handle after rotation.

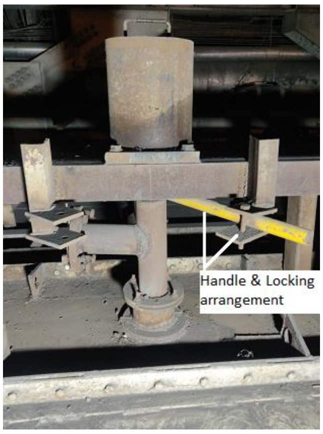

Figure 15: Handle and locking arrangement

9. Flexible hose connection with inlet and outlet header: To reduce the effort to rotate the SCAPH, coil inlet and outlet connecting pipes were replaced with flexible SS hose pipes.

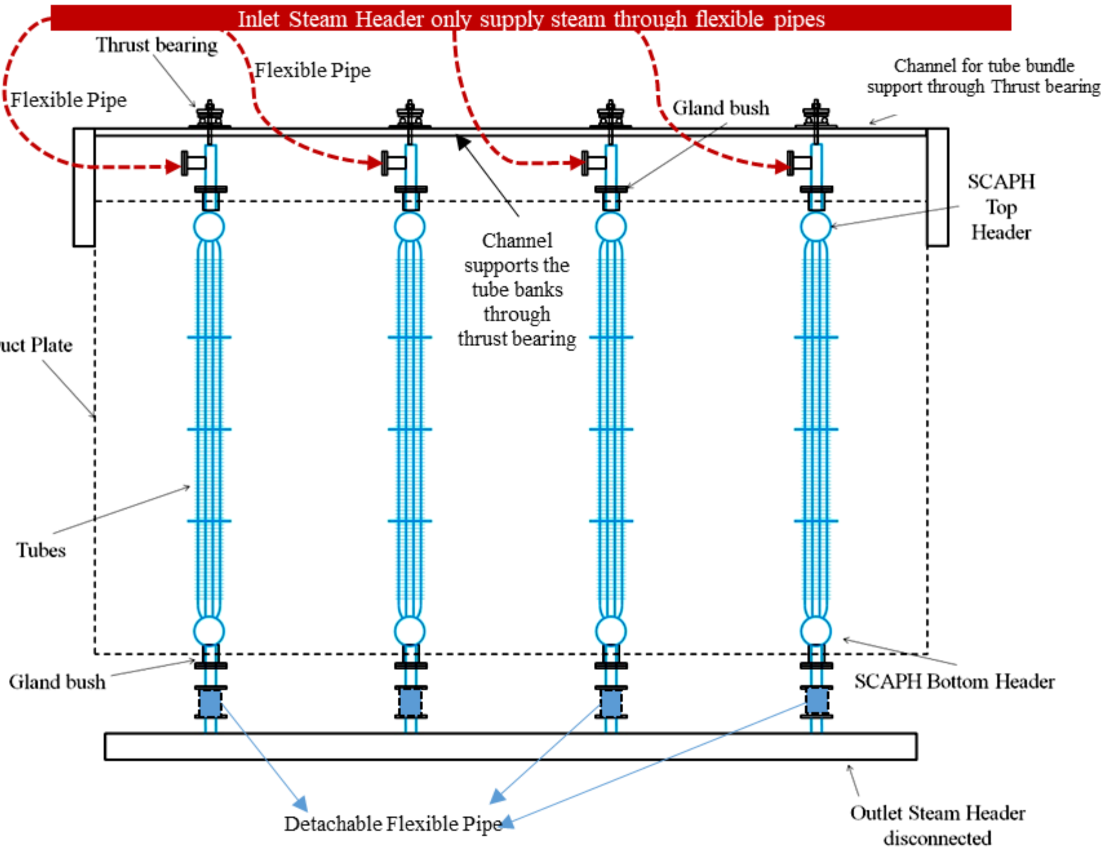

Figure 16: SCAPH Post Modification

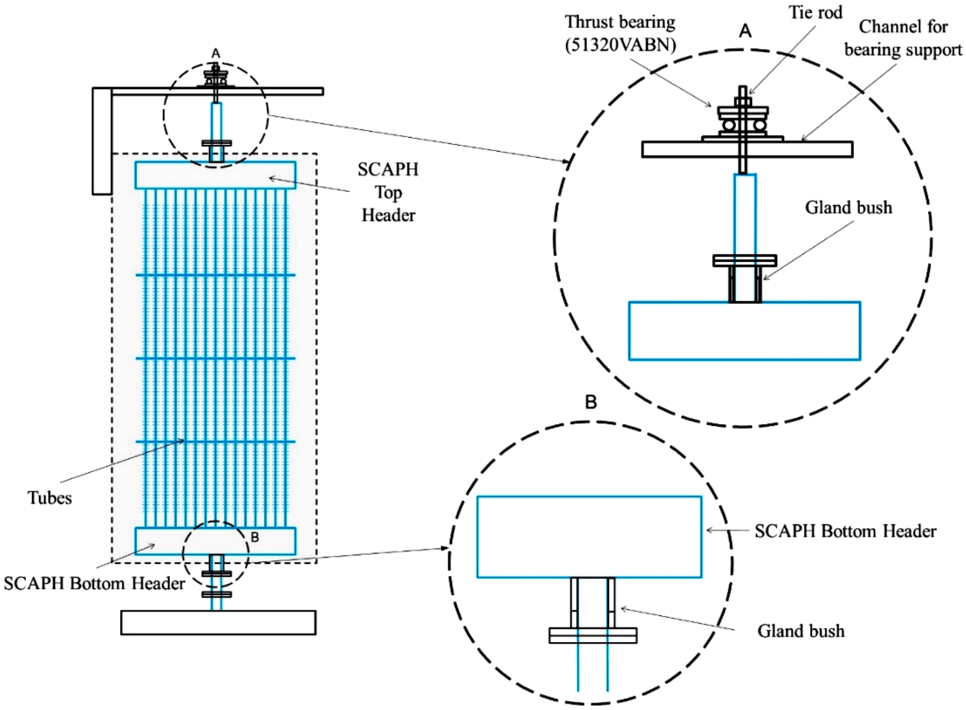

Figure 17: Exploded view of SCAPH post modification

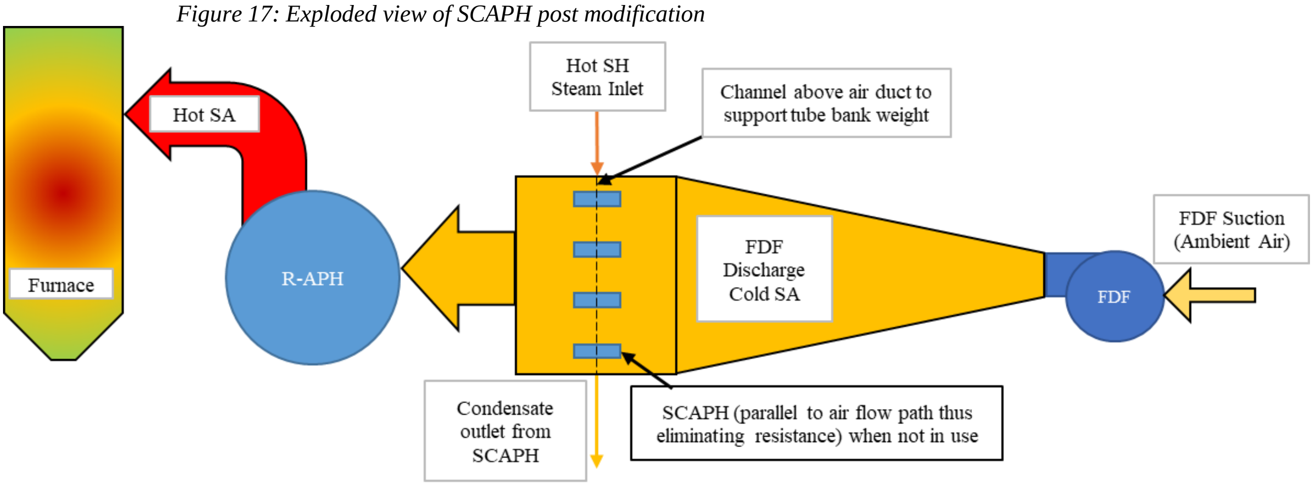

Figure 18: SLD of SCAPH at SPL post modification

Figure 19: SCAPH post modification in closed position at site (causing pressure drop)

Figure 20: SCAPH post modification in open position at site (causing no pressure drop)

C. Timeline and Cost of the Modification:

During planned shutdown of the units at SPL separate workforce was allocated for this project and the completion was successfully executed within 6 days of the overhauling (including the time of material expedition, material lifting, erection and final completion of the project activity). The whole cost involved in this design implementation for both the SCAPHs was approximately INR 1.50 lakhs only.

D. Cost Benefit Analysis:

The key driving force of any engineering design is the cost involved in executing it. If the cost involved or the payback time of the project is huge then the sustainability of the project becomes questionable. Moreover, the project site is selling power across India at the cheapest price so this innovative engineering design and modification had to be carried out at the lowest cost possible. The benefits envisaged from the implemented modification are tabulated in Table – 2. At 670MW load, same coal flow and same secondary air flow the forced draft fan A and B current cumulatively decreased by nearly 5.88 amperes which amounts to a saving of 46.2 kilowatt hour for the 3.3 kilovolt drive at a power factor of nearly 0.9 at site. Considering the average electricity tariff in India to be INR 3.50 per kilowatt hour then the amount for the electricity saved can be calculated to be nearly INR 14.16 lakh per annum. The payback period will be very miniscule and it can be calculated by dividing the project cost by the benefit amount derived which evaluates to less than two months. This profit is derived by pumping more electrical power, called NESO into the grid for the same amount of generation.

Table 2: Cost Benefit Analysis prior & post modification

Particulars	UOM	Before SCAPH Modification	After SCAPH Modification	Change (Δ)
Load	MW	670	670.1	0.1
Coal Flow	TPH	382	382.8	-0.8
Air flow	TPH	1663	1661.5	1.5
FD Fan A current	ampere	157.1	154.1	2.98
FD Fan B current	ampere	158.0	155.1	2.90
Secondary Air discharge pressure (A Side)	mmwc	191.0	174.3	16.7
Secondary Air discharge pressure (B Side)	mmwc	192.1	173.9	18.2
Actual Power Consumption of both FD Fans (Local measurement)	kW	1606	1560	46.2

IV. CONCLUSION:

Through this pioneering implementation of Rotary SCAPH the units are running healthy and there are no issues from the operational side since its inception. Maintenance post modification is also nil. During unit light up post tripping we take the rotary modified SCAPH into service and post unit synchronization we rotate the SCAPH by 90 degrees parallel to air flow path to nullify the pressure drop across it. This modification has reduced the auxiliary power consumption through decrease in forced draft fan loading.

This redesigning of SCAPH is first of its kind in India and abroad and has been in successful operation ever since the in-house retrofitting at SPL. The re-engineered Rotary SCAPH provides measurable and acceptable returns on investments and serves all its normal functionality as well as it has been a contributor to efficient fossil-fueled power generation. We have brought up a new concept of this often forgotten plant auxiliary to retain its value both on and off its operation.

V. ACKNOWLEDGEMENT

We extend our heartfelt gratitude to the extraordinary support which we have received from the top management at Sasan Power Limited with special mention to Mr. Anil Kumar Singh (CEO) and Mr. Sachin Mohapatra (Station Director).

We are thankful to the Rotary parts Mechanical Maintenance team and to all the skilled and unskilled manpower that were deployed for the systematic and planned project implementation.

VI. WAY FORWARD

Through this technical implementation all the thermal power stations equipped with this type of SCAPH system arrangement would be benefitted. We are open for discussion about all intricate details of this project with interested parties.

VII. ABBREVIATIONS

APC – Auxiliary Power Consumption
APH – Air Pre-Heater
BMCR – Boiler Maximum Continuous Rating
°C – degree Centigrade
Co. – Company
CEO – Chief Executive Officer
FDF – Forced Draft Fan
kg – kilogram
kW – kilowatt

MT – Metric Ton
MW – Megawatt
NESO – Net Energy Sent Out
Pa – Pascal
RPM – revolutions per minute
SA – Secondary Air
SCAPH – Steam Coil Air Pre-Heater
SH – Superheated
SLD – Single Line Diagram
SS – Stainless steel
TMCR – Turbine Maximum Continuous Rating
TPH – Ton per hour
UOM – Unit of Measurement

VIII. REFERENCES

[1] https://www.rotor.lublin.pl/en/research-and-development/rotary-air-preheater-elements/heating-baskets
[2] https://en.citizendium.org/wiki/Acid_dew_point