

Research Article

# Elimination of Soot and Rust from Nozzle Body In Order To Improve Quality and Productivity

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Accepted 12 March 2017, Available online 16 March 2017, **Special Issue-7 (March 2017)**

## Abstract

Due to unburnt hydrocarbons soot get generated during heat treatment. Generation of soot may be from different sources and from different effect in each condition. Basically soot gets generated due to coal burning, internal-combustion engine, power plant boiler, central steam-heat boiler, fireplaces and furnaces. In company basically manufacturing of nozzles takes place due to humid condition and deviation in process sticky soot formed and found at 100% visual inspection. Due to this problem company faces large productivity and financial loss. Objective of this project is to find out root causes of soot by using various quality tools and eliminate the soot and rust from nozzle body which frequently occur in pre monsoon and in monsoon season due to humid condition and detect in visual inspection process. Also improve productivity, efficiency and reduces overall cost of nozzle bodies.

**Keywords:** Soot, Humidity, Temperature SEM analysis, Pical, CR, DLSA, ECM, NaCl,

## 1. INTRODUCTION

Due to unburnt hydrocarbons soot gets generated during heat treatment. Generation of soot may be from different sources and from different effect in each condition. Basically soot gets generated due to coal burning, internal-combustion engine, power plant boiler, central steam-heat boiler, fireplaces and furnaces.

When N numbers of molecules undergoes many chemical and physical reaction within a few millisecond, amount of soot generation increased. It is very complex process.

Soot is found in powder form and generally occur due to unburnt hydrocarbon generally hydrocarbon used is acetylene. Soot is a powder-like form of amorphous carbon. Soot forms during incomplete combustion from precursor molecule such as acetylene. If this soot particles comes in contact with air, it generates rust on surface of the product.

## 2. Analysis

### SEM analysis

SEM analysis is chemical analysis of product. In this analysis overall checking of body take place in order to find out stress of chemical and other foreign particles which leads to soot and other defect.

SEM analysis of internal part of nozzle body takes place. Analysis of internal body with the help of microscope takes place. SEM analysis shows the traces of the Na in all parts at sac hole. Report of SEM analysis is as shown in figure below

Consolidated SEM/EDX Report - DLSAP Nozzles Pical Cleaning									
Description	Sample No.	Sample ID	Date	Site of Interest - 1		Site of Interest - 2		Observations	
				Image	Quant. Results	Image	Quant. Results		
Before USA	A1	NA	NA					No Soot or rust observed Parent material identified in back and front chamber	
	A2	NA	NA					No Soot or rust observed Parent material identified in back and front chamber	
	A3	NA	NA					No Soot or rust observed Parent material identified in back and front chamber	
	A4	NA	NA					No Soot or rust observed Parent material identified in back and front chamber	
After USA	B1	888	08/11/2015					Material deposit/aggregation is present in back hole and seal area Material aggregation is present in back hole and seal area Observation is consistent with SEM of Seal	
	B2	836	08/11/2015					Trace of carbon that is present in product No surface oxidation is present as per SEM analysis is consistent	
After USA	B3	882	08/11/2015					Material aggregation or deposit is present in seal area No deposit is visible in the nozzle No surface oxidation	
	B4	882	08/11/2015					Material aggregation or deposit is present in back hole No deposit is visible in the nozzle No surface oxidation	
	B5	881	08/11/2015					Material deposit or aggregation is present, Na is present in good amount	
USA + Pical + Reinspect	C1	888	08/11/2015					Material aggregation is present in back hole Material aggregation is present in back hole No surface oxidation in parent material	
	C2	281	08/11/2015					Material aggregation is present in back hole Material aggregation is present in back hole No surface oxidation in parent material Observation is consistent with SEM of Seal	
	C3	888	08/11/2015					Material aggregation is present in back hole Material aggregation is present in back hole No surface oxidation in parent material Observation is consistent with SEM of Seal	
	C4	888	08/11/2015					Material aggregation is present in back hole Material aggregation is present in back hole No surface oxidation in parent material Observation is consistent with SEM of Seal	
	C5	882	08/11/2015					Material aggregation is present in back hole Material aggregation is present in back hole No surface oxidation in parent material Observation is consistent with SEM of Seal	

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Description	Sample No.	Sample ID	Date	Size of Interest - 1		Size of Interest - 2		Observations
				Image	Quant. Results	Image	Quant. Results	
After Hardening	01	001	05.11.2016					Yellow residue present on the surface of nozzle body. The residue is not uniform. It is observed that the residue is not uniform. It is observed that the residue is not uniform.
	02	002	05.11.2016					Yellow residue present on the surface of nozzle body. The residue is not uniform. It is observed that the residue is not uniform. It is observed that the residue is not uniform.
	03	003	05.11.2016					Yellow residue present on the surface of nozzle body. The residue is not uniform. It is observed that the residue is not uniform. It is observed that the residue is not uniform.
	04	004	05.11.2016					Yellow residue present on the surface of nozzle body. The residue is not uniform. It is observed that the residue is not uniform. It is observed that the residue is not uniform.
	05	005	05.11.2016					Yellow residue present on the surface of nozzle body. The residue is not uniform. It is observed that the residue is not uniform. It is observed that the residue is not uniform.

Fig.1 Pical Cleaning

Findings of SEM analysis

- 1) Stresses of sodium and sodium chloride found during scanning electron microscope (SEM) analysis
- 2) Needs to find out root cause of stresses of sodium and sodium chloride in order to overcome soot defect

Further analysis and study of Na done for,

- 1) Sources of Na.
- 2) Why soot particles sticking to sac hole?
- 3) Why soot sticks to sac hole in humid conditions?
- 4) Or why soot issue pops up only Humid Conditions?
- 5) Physical properties Salt (MP, VP... etc.)
- 6) Is something melting and getting deposited at sac hole along with soot?

Na, NaCl melting theory

- 1) Theory put was uncleaned Na, NaCl at Pressure chamber, guide bore, inlet -hole melts during Carburizing process and due to gravity gets deposited at sac hole.
- 2) This molten solution gets contaminated with the soot particles generated in Carburizing and solidifies after process.
- 3) This solidified material remains in sac hole and does not get removed on aqueous Cleaning, and gets rejected as soot/rust in Hard Stage.
- 4) Carburizing temp. - 920°C, Melting point of NaCl - 801°C, Vaporising point of NaCl - 1400°

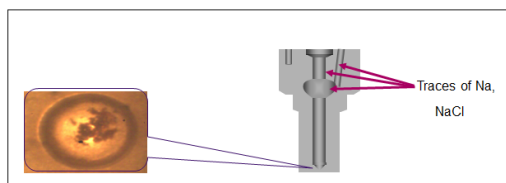


Fig.2 NA and NaCl melting theory

Validation of Na and NaCl melting theory

Further analysis and study of Na and NaCl done for,

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3. Trial

Validation Trial

- 1) 50 DSLA bodies after Aqueous Cleaning machine (Visually checked for NaCl traces) loaded in UDA for Carburizing.
- 2) And another 25 parts in seat side up position as shown in figure 3.6
- 3) 25 parts in normal loading position (Seat side down) as shown in figure 3.7 which
- 4) Figure 3.4 shows actual loading condition of trial
- 5) Result: From validation trial .25 parts which kept seat side up condition was clean after carburizing process. Because soot or molten metal which generate during carburizing process in this parts get fallen down due to gravity
- 6) And for another 25 parts which kept in normal condition was full of soot and rust because soot gravity effect soot falls down in to the sac hole and seat area as shown in figure



Fig.3 Part loading for validation trial

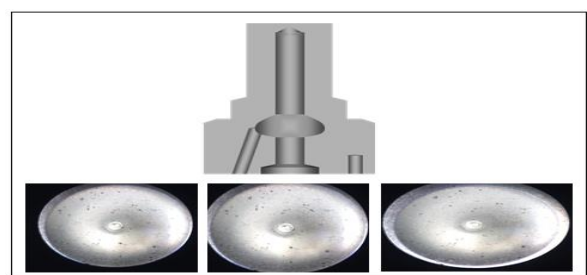


Fig.4 Parts with seat side up loading (Cleaned parts)

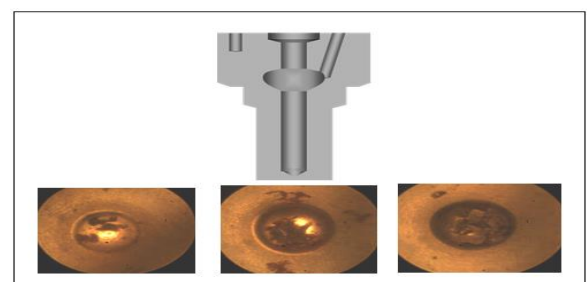


Fig.5 Parts with seat side down loading (with soot)

Re -Validation Trial

- 1) For revalidation 25 parts takes places for hardening which were not okay in validation trial
- 2) Apart from 25 parts 13 parts loaded in seat side up position as shown in figure
- 3) And 12 parts again loaded in normal loading position (Seat side down) as shown in figure
- 4) Results: From above revalidation trial again parts which were loaded in normal loading condition were full of soot and rust and parts which were loaded in seat side up position were clean

Trial Conclusion

- 1) From above validation of Na and NaCl melting theory several question arises viz.
- 2) Why soot/rust problem in certain conditions?
- 3) In humid conditions salt is more active and have more adhesiveness to the surface. Due to more stickiness of salt it gets stuck up inside the nozzle body and during heat treatment process it gets melt and mixed up with soot and stuck up at sac and seat of body
- 4) Why traces of NaCl at Guide bore, Pressure chamber, inlet hole. ?
- 5) Bodies are loaded in aqueous cleaning like seat side down position, jets at 10 bar hit sac hole while guide bore and Pressure chamber gets cleaned by return flow. Pressure chamber, inlet hole and guide bore cleaned at low pressure due to low pressure cleanliness is not takes place effectively

NaCl removal actions

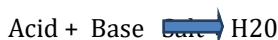
Sources of Na and NaCl

ECM Process

- 1) Electrochemical machining process is major source of Na and NaCl.
- 2) Three Electro chemical machining machines are available in shop
- 3) RT ECM & ATMO for DSLA
- 4) CR ECM line for CR

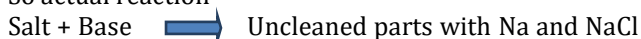
Picsal Cleaning

Picsal cleaning is basically neutralization operation in which stresses of Na and NaCl remove with the help of chemical picsal. As per neutralization concept acid should be react with base in order to give output of salt and water



In actual condition in picsal cleaning i.e. Neutralization there is use of base(NaOH)

So actual reaction



stresses

100% DSLA parts cleaning trough picsal cleaning process takes place

3.6 Immediate corrective actions

Immediate corrective action taken place in order to avoid Na and NaCl stress in nozzle body .This actions results tremendous reduction in soot and rust of the nozzle body. First action took on round table ECM (RT ECM) line and second on Picsal (neutralization) line.

3.6.1 RT ECM

- 1) Immediate corrective measures on RTECM (round table) .Maximum DSLA parts produced on this machine.
- 2) Water bath after RT ECM made more effective to remove NaCl.
- 3) Figure below shows the before and after action situation of RT insulator part dipping



Fig.6 Corrective action on RT ECM line

- 1) Flowing water connection added to tank in order to remove NaCl which is used for machining operation and stick inside the nozzle body during machining due to humid atmosphere
- 2) Normal water is replace by deionized water with added dimol chemical (alkaline cleaner) which is used for rust protection
- 3) Set waiting time strictly less than 30 minutes between ECM and Picsal cleaning i.e. Neutralization station as per specification
- 4) RT ECM Cleaning station made more effective by using
- 5) DI water for cleaning
- 6) Heating Provision for cleaning tank.
- 7) Use of electrodes for effective cleaning of Pressure Chamber

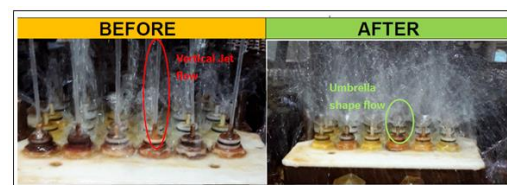


Fig.7 Effective jet cleaning

Picsal Cleaning (neutralization)

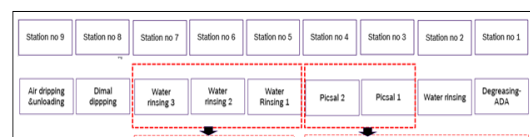


Fig.8 Picsla Process over view

**Table 1.**Picsal Specifications

S.N	Operation	Time in Min	Bath No	Chemical	Temperature
1	Degreasing ADA	Dipping 2.5	1	ADA	70+/-5 <sup>o</sup>
		Air 0.5			
2	Water Rinsing	Dipping 1.5	2	Rinse water	Room temperature
		Air 0.5			
3	Picsal Cleaning	Dipping 1.4	4	Picsal Ad (NaOH)+ water	70+/-5 <sup>o</sup>
		Air 1	5		
4	Water Rinsing	Dipping 1.5	6	Running water	Room temperature
		Air 1	7		
5	P3 Dimol	Dipping 2.5	9	P3 Dimol+ water	85+/-5 <sup>o</sup>
		Air 1	8		
6	Air dripping	Dipping 2.5	10	Air	Room temperature

Picsal Process had lot of deviations. Basically station number 3 and station number 4 had deviations .For station no 4 (including bath no 6,7,8) Rinsing time was only 30 sec as against 90 sec. causing ineffective rinsing and Removal of Na, NaCl. For station number 4 made rinsing time 90 second from 30 second useful for effective cleaning of Na and NaCl stresses. Second action was on station number 4 which is picsal cleaning. Initially concentration for picsal cleaning as per specification was 150+/-50 grams/liters (average 175 grams/liters)

Trail 1 Increase concentration above 200 grams/Liters

- 1) For trial 1 prepared bath with concentration 220 grams/liters and observe for 1 day
- 2) as per observation soot drastically increased
- 3) Soot quantity for DSLA parts increased average from 900 pcs to 1800 pcs per day

Trail 2 Concentration Decrease 60 to 100 grams/liters Range

- 1) By taking reference of trial 1 and also info sharing with technical expert for new trial concentration reduce up to 60 to 100 grams/liters range
- 2) After reducing concentration soot quantity reduced by 70%
- 3) Found 78 Parts with soot and rust in inspection
- 4) After validation of this trial made concentration between 60 to 80 grams/liters

UDA (Heat Treatment area)

In UDA area carburizing and hardening takes place. For DSLA parts carburizing and hardening is two different processes and for CR parts carburizing and hardening takes place at a time in same furnace

Trial 1 Dedicated Furnace for heat treatment

- 1) Four furnaces available for heat treatment namely Furnace A, Furnace B Furnace C Furnace D

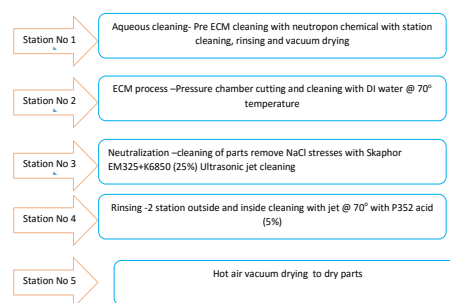
- 2) All furnaces were open for all this processes i.e. carburizing , hardening and carburizing & Hardening
- 3) Current condition furnace D is dedicated for only hardening of DSLA parts and Furnace a and c is running for carburizing of DSLA parts and Furnace B is running for Carburizing and Hardening of CR parts.
- 4) Use of dedicated furnace results in loose and non-sticky soot and also soot quantity in parts was much lower.

Development of alternate cleaning station

- 1) As after lot of analysis found that picsal cleaning machine (Neutralization) is running with lots of deviations and results in defective parts which increases overall cost and affect quality of product and also non standardize machining as per plant norms
- 2) In order to standardize manufacturing line with Bosch international plant norms (IPN) requirement of improved process of neutralization or develop parallel process which gives sustainable results and improved quality parts in
- 3) For the development of new parallel line took reference of existing dedicated CR ECM line. Compared both processes with various parameters like machining , time , chemical use comparison of both machine for processes and chemical use is as given below.

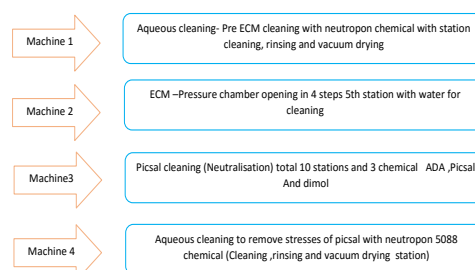
Comparison of CR ECM line with DSLA process

Existing CR ECM line



**Fig.9** Existing CR line

DSLA process existing



**Fig.10** Existing DSLA process

Chemical comparison

**Table 2.**Chemical comparison of ECM machines  
Comparison Result

Element	RT ECM	ATMO ECM	CR Line
Electrolyte for ECM	NaCl without HCL dosing		NaCl with HCl dosing
Cleaning After ECM	Normal cold water		DI water at 70 °C with air blowing
Neutralization	Picsal line with Picsal AD and Barrel rotation		Separate bath with Eskaphor K325/6850 and Ultrasonic jet cleaning
Cleaning After neutralization	Neutropon 5088		Eskaphor P 352
Waiting	Standalone machines with waiting in between operations		Continuous line

In process comparison we can see as CR ECM line is dedicated for CR and continuous line so no waiting time between process while on DSLA line for all processes stand-alone machines with waiting in between operations which leads rust in parts

At ECM station:

- 1) CR ECM - Chemical NaCl with HCl dosing and cleaning @ 700 with DI water
- 2) RT ECM - NaCl without HCL dosing and cleaning with cold water
- 3) As for CR ECM NaCl with HCL dosing proper neutralization takes place while at RT ECM line no proper neutralization of parts results in stresses of NaCl at inner side of nozzle body. Also cleaning of parts after ECM i.e. Pressure chamber cutting process for CR ECM cleaning takes place with hot DI water with temperature 700 C and for RT ECM with cold water which results in ineffective cleaning of parts.

For neutralization

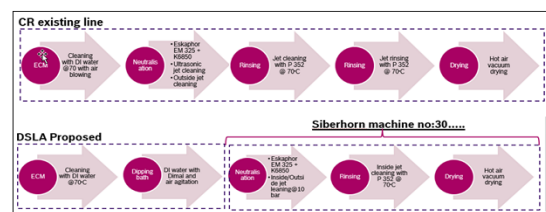
- 1) CR ECM - Separate bath with Eskaphor K325/6850 and Ultrasonic jet cleaning
- 2) Picsal Line-Picsal line with Picsal AD and Barrel rotation
- 3) If we compare both chemical use of Eskaphor which is strong acid with ultrasonic effect result in high quality cleaning and for picsal line use of PicslaAD (NaOH) chemical with parts in jumbled condition in barrel which dip in acid bath results in ineffective cleaning.

Cleaning After neutralization

- 1) CR ECM- Eskaphor P 352 with 8 bar pressure
- 2) Aqueous Cleaning - Neutropon 5088 with 10 bar pressure
- 3) Both chemical use for machine are alkaline rinsing media with purpose of cleaning stresses of neutralization/picsal cleaning

Proposal of alternate process in line with IPN

- 1) From above comparison of DSLA parts process with CR parts process we can conclude there are lots of deviation in the DSLA process which results in major defect so development of new line or major/ minor changes in existing process of DSLA are must in order to overcome this defects
- 2) After lots of discussions and meetings with management peoples got approval of trial of 15 days
- 3) Trial details as follow ( process sequence and chemical use )

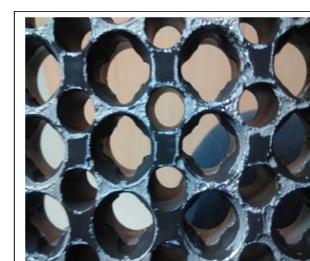


**Fig.11** Proposal of New line

- 1) Major deviation were in post ECM cleaning we made changes for DSLA process
- 2) In DSLA process for post ECM there were 2 machines namely Picsal cleaning and Aqueous cleaning
- 3) We skip the picsal cleaning and replace the silberhorn (aqueous cleaning) machine chemical i.e. Neutropon 5088 which is less concentrated alkaline cleaning and rinsing media with Eskaphor k6850 for cleaning and Eskaphor p352

Trial Result

- 1) Run this process for 2 days and analyze the results for further development
- 2) Quality of parts with new process is improved with effective cleaning and same as CR ECM line parts which was acceptable
- 3) Chemical is suitable for machine and machine is running without any interruption
- 4) Major deviation found in trial with parts loading plate of aqueous cleaning line
- 5) Plate for aqueous cleaning is shown in figure. As material for plate is aluminum which is react with acid Eskaphor k6850 result in erode of plate figure below shows erodification on aluminum plate due to reaction with new acid eskaphor k6850



**Fig. 12**Erodification of aluminum plate

Validation of new neutralization line

- 1) As per company norms if there is any change in process or replacement of machine or new machine there are several many tests for validation
- 2) For ECM line validation as per trial order requirement for "HIGH PRESSURE PULSATION TEST" (HPPT) in order to validate process capability
- 3) HPPT is "High Pressure Pulsation Test" which is mandatory to perform after every change in the manufacturing process to check for deviation in process parameters.
- 4) During this, the trial parts are tested under the same conditions that actually prevail in diesel engines i.e. nozzles are tested for operating under high pressures. It is a destructive type of testing.
- 5) A "Maximator" machine is used to show the graph of Pressure variation with respect to the no of pulsation cycles in different pressure stages.

Table 3. HPPT Procedure

Activities for preparing the HPPT parts		
Step	Activity	Remarks
1	Nozzles bodies ( before AGIE ) to be identified( with numbers) for the defect ( worst parts to be consider)	Quantity 100 pcs
2	Measurements of the Nozzles bodies (Guide bore Diameter Dmin and Dmax)	100% checking
3	Define the needle sizes for clearance & interference	
4	Manufacturing of the needles	( special needles-needle with step on guide )
5	Measurement of needles	100%
6	Matching of the Body & needles	
7	Pre-Stroke of the needle	( using dummy needles
8	Putting the actual needles in to the body.	

4. Results

From above analysis changes and new development result in tremendous decrement in soot quantity parts. Below chart shows the result of soot and rust results in terms of quantity in terms of scrap cost and in terms of productivity. Also comparison with last 2 years data.

Table 4. Year wise comparison

Year	2014	2015	2016
Soot fallout after HT	73000	84500	107706
Scrap after repair		15798	4536
Scrap Cost	0	897010	257554
Productivity loss %	3.5	4.26	1.15
Repair cost	0	141960	198432
Scrap+Repair cost in INR		1038970	455986

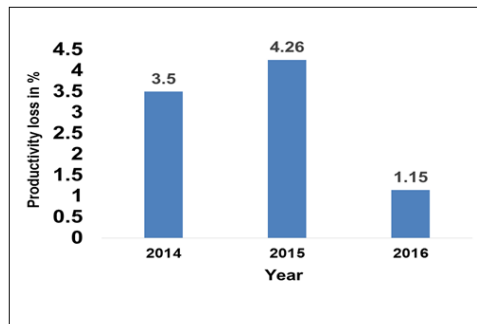


Fig.13 Result of Productivity

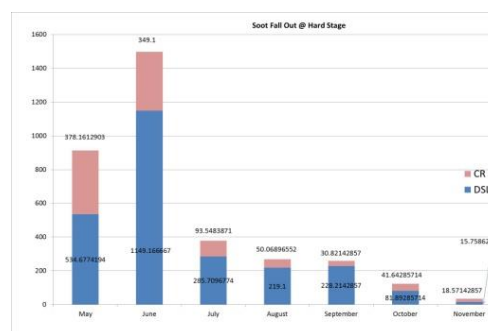


Fig.14 Monthly soot fall out

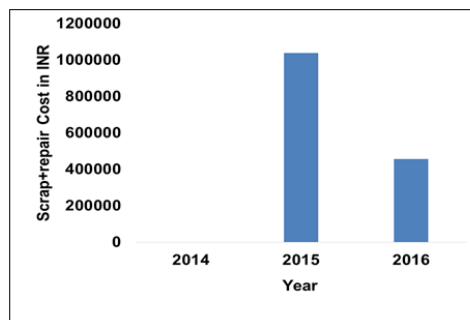


Fig.15 Comparison of overall cost of scrap and repair

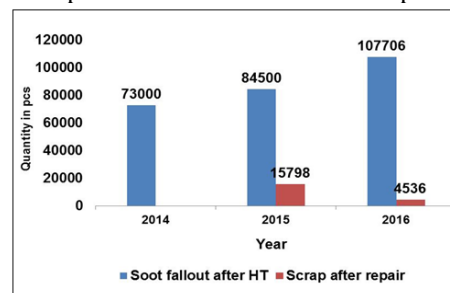


Fig.16 Total soot fallout and Scrap parts graph

5. Benefits

- 1) Manpower Saving: 3 per day →@4 % increase in Soft Stage Productivity.
- 2) Energy Saving: 222 kw/day
- 3) Water Conservation: 15K liters per day.
- 4) Elimination of 3 Chemicals (ADA, Picsal, Dimal) and EHS risks.
- 5) Reduction in Soot.- 70% reduction

- 6) Standardization of processes inline CR nozzle and IPN.
- 7) Space Saving: 500 sq. feet

### Conclusion

By using several quality tools and trial error analysis effect of soot and rust in nozzle body during rainy and humid condition successfully eliminated. Also we eliminate root cause of sticky soot and develop alternate machine in order to avoid future defect generation which leads in improvement of quality and productivity and cost saving.

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