ISSN No:-2456-2165

Control Atmospheric Brazing Technology for Heat Exchangers Manufacturing

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Abstract:- Control Atmospheric Brazing (CAB) for aluminum heat exchangers are widely used in auto ancillary industries. In the new era of Industry 4.0, development of auto industries are expected to grow exponentially and hence HVAC&R industries are supposed to grow simultaneously. The widen use of CAB process is the new universally accepted technology or process for mass production of the heat exchangers. This process enables the auto vehicle to reduce its weight by reducing heat exchanger weight, enhance the performance in compact design of HVAC, and accelerate the production rate to meet the market demand. Suitable different aluminum alloy grades are introduced for CAB Brazing technology and sheet metallurgy and other applications have been derived. Aluminium alloy was selected as it is lightweight and can be manufactured and brazed easily. Aluminium Potassium fluoride flux recent development has enabled the possibilities of molten aluminum filler metals during brazing. There are several processes identified and developed over the time for fluxing on pre assembled non brazed heat exchangers.Application of flux is opening the wide range of possibilities to thermochemical reactions in the CAB process. In this project & literature survey I am studying this process in detail which includes real industrial application, information, process design, Basic details of the product design of heat exchangers suitable to CAB brazing. My main focus to study this will consist of the thermal engineering application in product and its process as well. I would like to expose myself to identify the new possibilities in CAB technology.

I. INTRODUCTION

For decades now, there are significant revolutions in automotive industries and so in mobility. The science and technology have evolved rapidly and changed the concept of traditional design of copper/brass heat exchangers in automobiles and trucks. The traditional design have been almost completely replaced by brazed aluminum units.Weight savings and cost advantages were the motivators for this change.Later it enabled advances in technologies which were known as aluminum vacuum-brazing technology.In further progression in technologies and science this methods further advanced as aluminum controlled atmosphere brazing (CAB) technology.It was gesticulating the eye of industries towards savings in production costs, and this has now become the new standard of manufacturing process for the high-volume joining of most automobile heat exchanger assemblies. Current predictions are that CAB will play an increasing role in the growing market for brazed aluminum condensers in the heating, ventilation, air conditioning and refrigeration (HVAC&R) sector, where aluminum is expected to once again replace copper.

The CAB aluminum brazing process is characterized by:

(1) Vacuum based, without flux controlled atmosphere through inert gases.
(2) With usages of Aluminum Potassium fluoride (flus) in an inert gas chamber with an allowable limit of oxygen.

Aluminum brazing is now the preferred process for the production of automotive heat exchangers such as radiators, condensers, evaporators and heater cores. Metallurgical advantages as good corrosion resistance, formability and high thermal conductivity make aluminum an ideal material for the construction of these heat exchangers.

Aluminum brazing involves joining of components with a brazing alloy, that is an aluminum alloy (Al-Si) whose melting point is appreciably lower than that of the components. This brazing alloy is usually placed adjacent to or in between the components to be joined and the assembly is then heated to a Temperature where the brazing alloy melts but not the components. Upon Cooling, the brazing alloy forms a metallurgical bond between the joining surfaces of the components. In automotive heat exchanger applications, This filler metal is supplied via a thin sheet or clad on a core alloy. The core provides structural integrity while the low melting point Al-Si cladding alloy melts and flows during the brazing process, to provide upon cooling a metallic bond between the components. It is usually necessary to employ a flux in brazing aluminum to remove the native oxide film present on all aluminum surfaces.

The flux must be capable of displacing the oxide film barrier during brazing to allow the filler metal to flow freely and must prevent the surfaces from deoxidizing. Many fluxes and brazing techniques have evolved over the Years, but one process that is now recognized worldwide is the NOCOLOK flux brazing process.

The present paper describes the process of CAB and its process & methodology in detail. This thesis would also emphasize on the metallurgical and other aspects of the CAB brazing in detail.

1.1 Heat Exchangers

Heat exchangers is the system used to transfer the heat among the fluids. In automobiles there are different kinds and types of heat exchangers. The design and manufacturing concepts are based on the functionality and requirements of the products. The most common type of heat exchangers used in automobiles are as below:-

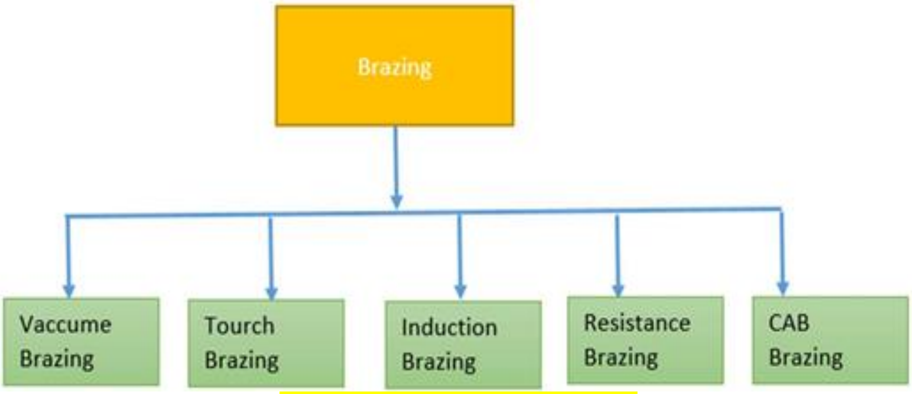
1. Radiators
2. Charge air cooler
3. Condenser
4. Heater core
5. Evaporator
6. Oil cooler
7. Transmission cooler
8. EGR Cooler

The Manufacturing of the above heat exchangers are widely dependent on the CAB NOCOLOK process, as it is the most effective and efficient process for mass production.

1.2 Brazing

Assembly of two metal parts with fusion of a filler metal which has a melting point lower than the one of the two parts to be assembled without melting of the core metals.

Most commonly Brazing can be done by below process:-



General Classification of Brazing

1.3 Control Atmospheric Brazing

The CAB, as the name explained controlled atmospheric ,so therefore in this type of Brazing, control of atmosphere, during the brazing it is essential to remove the oxygen from the muffle or in Brazing chambers and for that inert gases are used widely. As inert gas nitrogen is available almost 78% in air, therefore nitrogen is used very often for controlling the atmosphere inside the brazing chambers.

Aluminum brazing is now the preferred process for the production of automotive heat exchangers such as radiators,condensers, evaporators and heater cores. Good corrosion resistance,formability and high thermal conductivity make aluminum an ideal material for the construction of these heat exchangers. Aluminum brazing involves joining of components with a brazing alloy, that is an aluminum alloy (Al-Si) whose melting point is appreciably lower than that of the components. This brazing alloy is usually placed adjacent to or in between the components to be joined and the assembly is then heated to a temperature where the brazing alloy melts but not the components. Upon cooling, the brazing alloy forms a metallurgical bond between the joining surfaces of the components. In automotive heat exchanger applications, this filler metal is supplied via a Thin sheet or clad on a core alloy. The core provides structural integrity while the low melting point Al-Si cladding alloy melts and flows during the brazing process, to provide upon cooling a metallic bond between the components. It is usually necessary to employ a flux in brazing aluminum to remove the native oxide film present on all aluminum surfaces.The flux must be capable of displacing the oxide film barrier during brazing to allow the filler metal to flow freely and must prevent the surfaces from reoxidizing. Many fluxes and brazing techniques have evolved over the years, but one process that is now recognized worldwide is the NOCOLOK flux brazing process.

Main features :

- Providing the flexibility in design for heat exchangers for various ranges of dimensions.
- As the phenomena consists of metallurgical chemistry therefore good thermal conductivity between metals.
- Give the freedom to have different material in the assy process of heat exchangers.
- Can be able to make the thousands or more of joints at a time in one operation. ● Minimal residual constraints.

1.4 WHY CAB ?

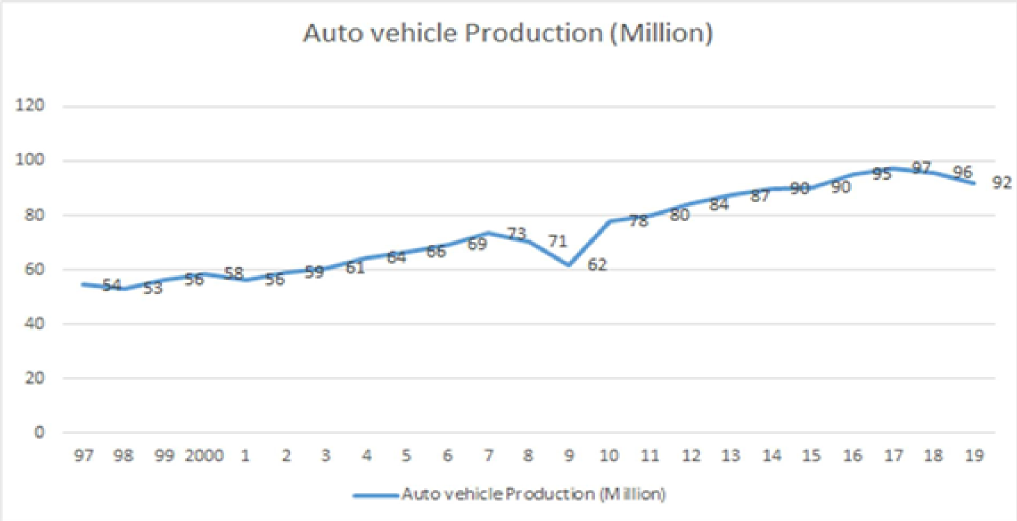
1. Heat exchangers have multiple or thousands of contact points to join, and in mass production it is not possible to connect all joints so quickly with accuracy and precision. CAB process is providing the solution for above constraints.
2. In the CAB process the hourly output can be from 100-400 HEX per hour based on its size.
3. The Quality and metallurgical requirements from heat exchangers are met by CAB process.

4. The CAB process is economical and ROI is least.

II. MARKET RESEARCH AND ANALYSIS

After globalization and simplification and agreement on trade deals among the countries there is significant upliftment in industrial growth and market expansion. Therefore the mobility and transportation has become the key for logistics and supply chain.

The change in market scenario was welcomed by many industrialists and many new industries began in the automobile by seeing the potential market size and opportunities to grow. the growth in sales of automotive vehicle since 1997 to 2019 can be seen in below graph.

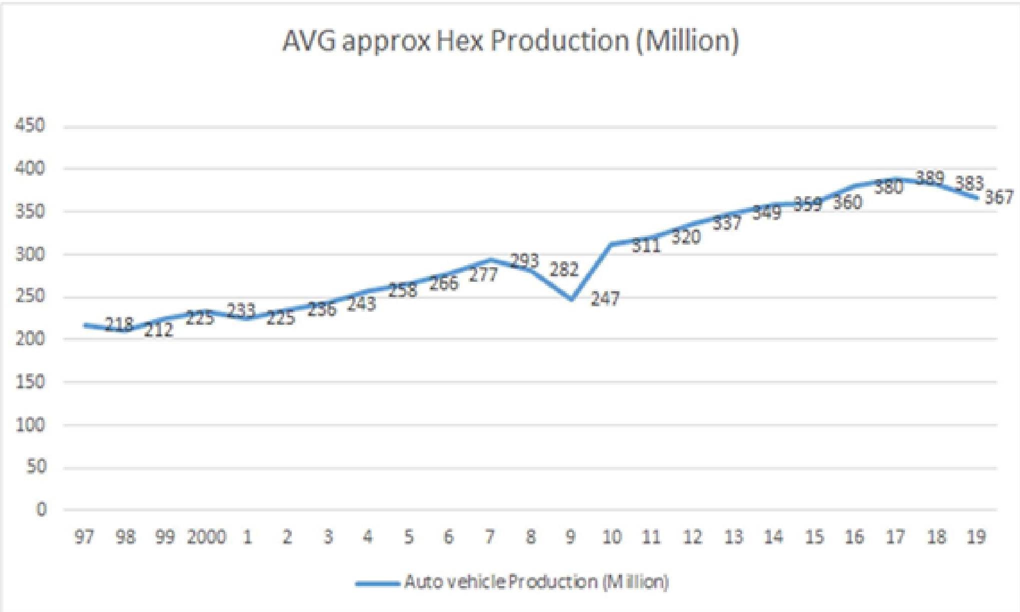


Trend of Year wise global passenger automotive CAR production (in million)

The development and growth in automotive vehicle production has equally affected the market of ancillaries of automotive vehicles and HEX was not different from its domain.

Hence the growing market and demand raise is given the opportunity to find the mass production solution and lean enterprise to meet the demand of heat exchangers for auto vehicles.The evolution of Brazing and then CAB is one of the outcomes of this evolution.

You can see the below table and graph for average approx Heat exchangers demand per year:-



Trend of Year wise global HEX Manufacturing for passenger automotive CAR (in million)

Year	Production	Auto vehicle Production (Million)	Approximate Heat exchanger (Million)	Change YOY
1997	5,44,34,000	54	218	—
1998	5,29,87,000	53	212	▼ 2.7%
1999	5,62,58,892	56	225	▲ 6.2%
2000	5,83,74,162	58	233	▲ 3.8%
2001	5,63,04,925	56	225	▼ 3.5%
2002	5,89,94,318	59	236	▲ 4.8%
2003	6,06,63,225	61	243	▲ 2.8%
2004	6,44,96,220	64	258	▲ 6.3%
2005	6,64,82,439	66	266	▲ 3.1%
2006	6,92,22,975	69	277	▲ 4.1%
2007	7,32,66,061	73	293	▲ 5.8%
2008	7,05,20,493	71	282	▼ 3.7%
2009	6,17,91,868	62	247	▼ 12.4%
2010	7,78,57,705	78	311	▲ 26.0%
2011	7,99,89,155	80	320	▲ 3.1%
2012	8,41,41,209	84	337	▲ 5.3%
2013	8,73,00,115	87	349	▲ 3.7%
2014	8,97,47,430	90	359	▲ 2.6%
2015	9,00,86,346	90	360	▲ 0.4%
2016	9,49,76,569	95	380	▲ 4.5%
2017	9,73,02,534	97	389	▲ 2.36%
2018	9,56,34,593	96	383	▼ 1.71%
2019	9,17,86,861	92	367	▼ 5.2%

Year on year global CAR production trend

2.1 Brazing History and Industrial evolution

Since 1568, when Italian goldsmith BENVENOTO CELLINI was described and explained the brazing process , since then it is in practise in different mechanical processes.

The continuous improvement and dynamic changes in the process and technology has grown in 4 centuries. But the exponential experiment and growth had happened in the 19th and 20th century when the industrial revolution happened. Specially after the second world war the world has established significant market expansion and parallel development.

Mass production of heat exchangers through brazing got the wing when american scientist found the biggest oil reserve in the middle east, which gave the far speculation of the future of auto vehicles.The discovery and research has started to get the solution for mass production methodology though brazing and so therefore, CAB through furnace was surfaced. Since then there have been a lot of improvements, and technological upgradation has happened in this process.

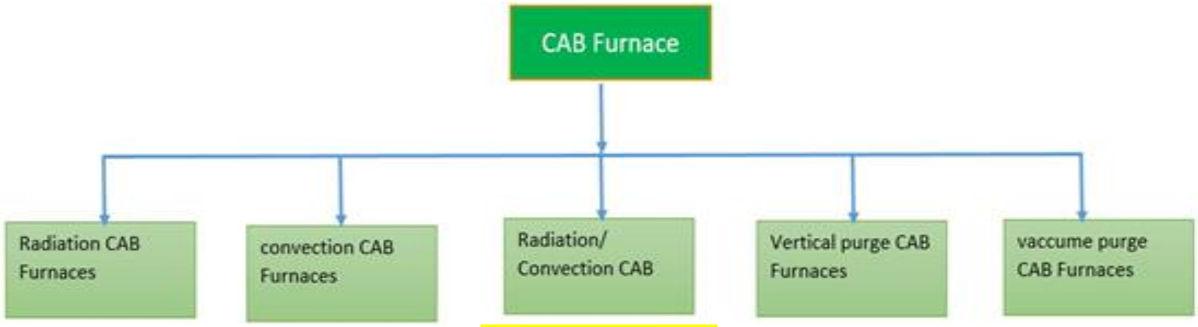
2.3 CAB Furnace

Control atmospheric furnaces are specifically designed for mass production of the heat exchangers for auto vehicles. The CAB furnace design specifically in such a way that output of the furnace could be significantly high. therefore it is designed in the sub section of the entire process, which has been classified with different name and specific process controls.

It has degreaser, Fluxer, Dryer, Pre heating, Brazing and cooling sub sections.The details of the each sub section and its importance has been described in details as below:-

2.4 CAB Brazing Furnace classification

Control atmospheric Brazing (CAB) is done through the specific designed furnaces. which consists of the several processes within, which are mandatory to have for good brazing. The details of the entire process will be explained in the pages below. CAB Brazing can be done through the various type of furnaces, which can be classified by its working phenomena and technologies as below:-



Classification of CAB

Despite having various types of the Furnaces, the fundamental process consists of the common process but fundamentally there are some working level differences. The common processes will be explained below in details but by having the comparison, it will be easier to understand the each kind of the CAB Brazing furnace

Furnace type	Radiation braze	Convection preheat / radiation braze	Convection braze
Time to braze	High	Medium	Low
Product intermixing	Low	Medium	High
Temperature uniformity	Medium	Medium/High	High
Atmosphere consumption	Low	Low	Medium
Required maintenance	Low	Low	Medium
Brazing efficiency	Medium	Medium/High	High
Flexibility	Low	Medium	High
Cost	Low	Medium	High

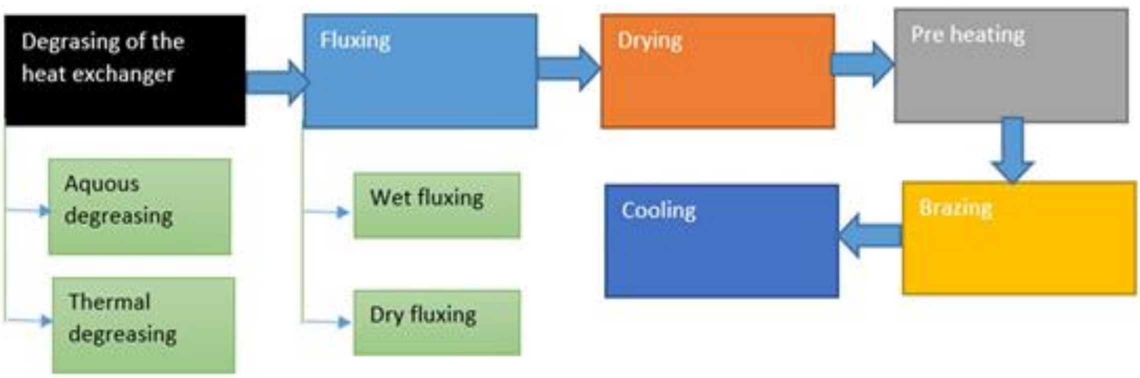
CAB Comparison Table

Temperature profile which is somehow similar in all kinds of CAB furnaces, which is derived by the melting temperature of the clad material and base material. The profile is derived by the DOE (design of experiments). temperature profile are based on the

1. Size and dimension
2. Material type
3. Weight of the aluminium and brazing fixture.
4. Furnace size and capacity.

The common profile which is widely established and accepted for the CAB brezing is as below:-

Process flow of CAB furnace:-



Generic CAB process flow

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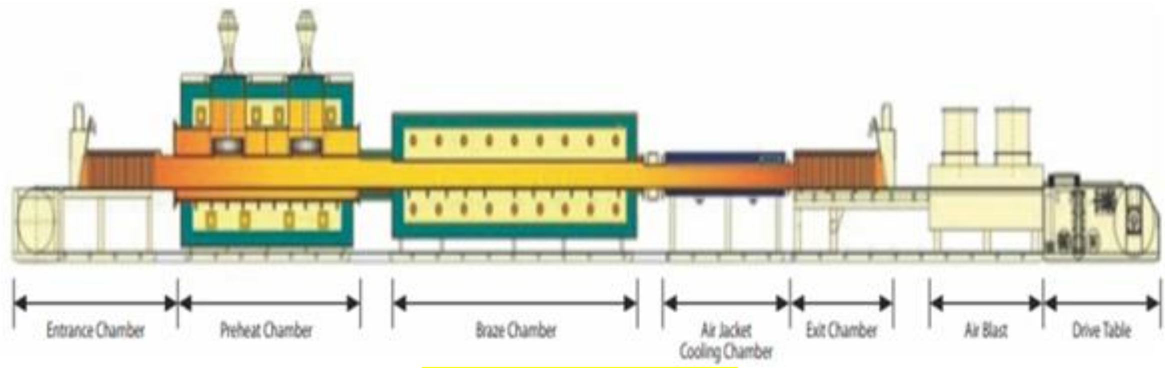
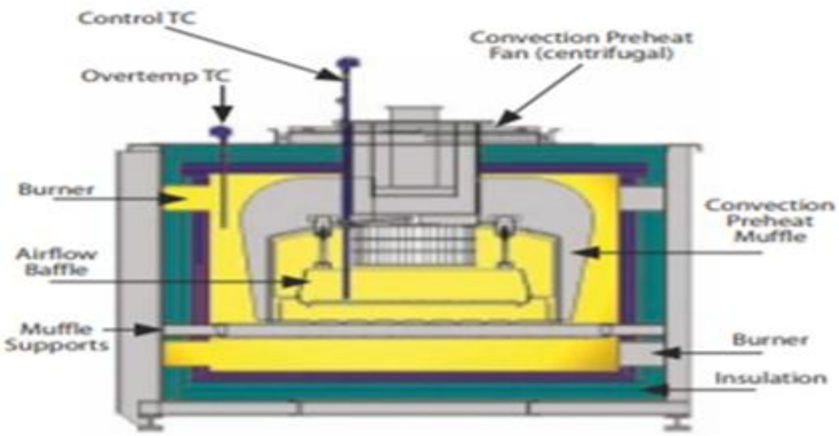
The front view of the simple cab Furnace design:-



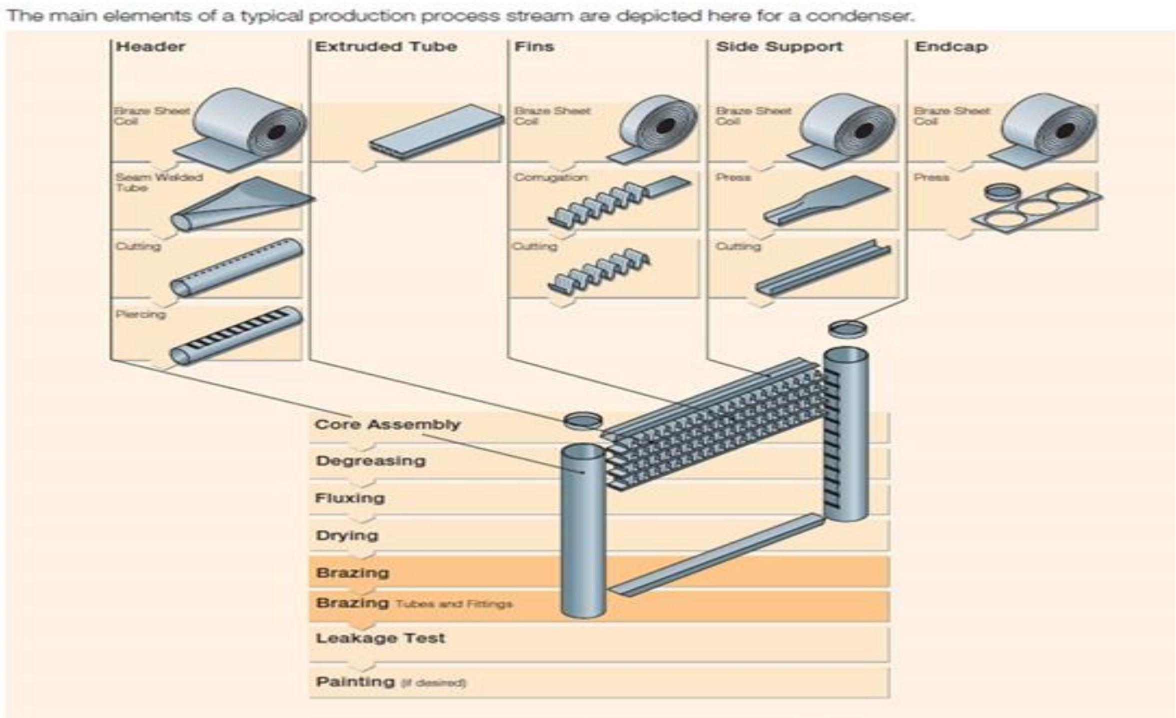
Generic CAB Furnace design

Cross section of furnace muffle design is described as below:-



Cross sectional of CAB Furnace

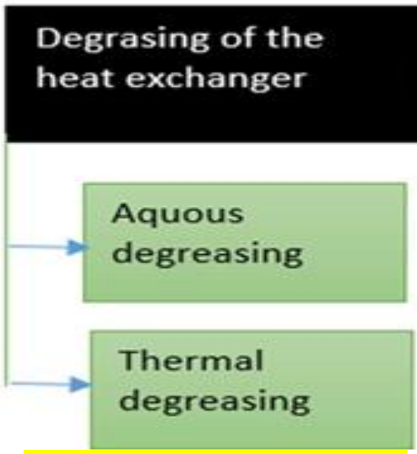
The Main element of the typical production process of the Condenser (heat exchangers. By seeing this photograph, one can easily understand the process.



Each process in control atmospheric brazing has their own significance and importance. The details of each process is described in sequence.

2.5 Degreaser

Degreaser is the equipment which is used to remove the lubricating oil from the assembled or in non-assembled child components. Usually this process can be done in two ways



Classification of degreaser for CAB

Thermal Degreaser

A Thermal Degreaser Oven will thermally remove the lubricating oils present on the heat exchanger from prior fabrication stages. The assembled and fixtured product will be placed on the oven conveyor for processing. The oven will typically operate at 250 – 300°C to vaporize the oils. If light evaporative oils are used in the process, the vapors from the products are oxidized in the combustion chamber. If heavier lubricating oils are used, an incinerator at the oven exhaust may be required. The products must then be cooled back to ambient temperature prior to the fluxing process.

General Assy of Thermal degreaser with afterburner

Function Surface cleaning of the HEX before application of flux.

(Role/objectiv e) What happen During the forming of fins or sub assy parts there are specific **if we won't** vanished or evaporative oil are used , so the surface of

degrease assembled parts having significant amounts of oil which wont let flux homogeneously apply on the surface. And if Flux won't apply in homogeneous order , oxidation will appear and brazing will not meet the required quality criteria.

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Working method

Thermal degreasing works by elevating the temperature of the workpiece so that lubricants present on the surfaces will be flashed off. This procedure only works with special types of lubricants known as evaporative or vanishing oils. Vanishing oils are light duty lubricants used mostly for the fabrication of heat exchanger fins, although they are now finding uses in the stamping and forming of other heat exchanger components. Lubricants not designed for thermal degreasing should not be used. These could leave behind thermal decomposition products and carbonaceous residues which have the potential to degrade product appearance and accelerate corrosion. HEX are assembled and fitted, they are loaded either batchwise into a specially built thermal degreasing oven, or continuously on a belt through a thermal degreasing station. In either case, the heat exchangers are exposed to a suitable timetemperature cycle to flash off the lubricants. The lubricant suppliers can recommend suitable cycles. The exhaust gases may need to be treated (scrubbed or incinerated) depending on local exhaust policies. The heat exchangers are then fluxed after the thermal degreasing cycle.

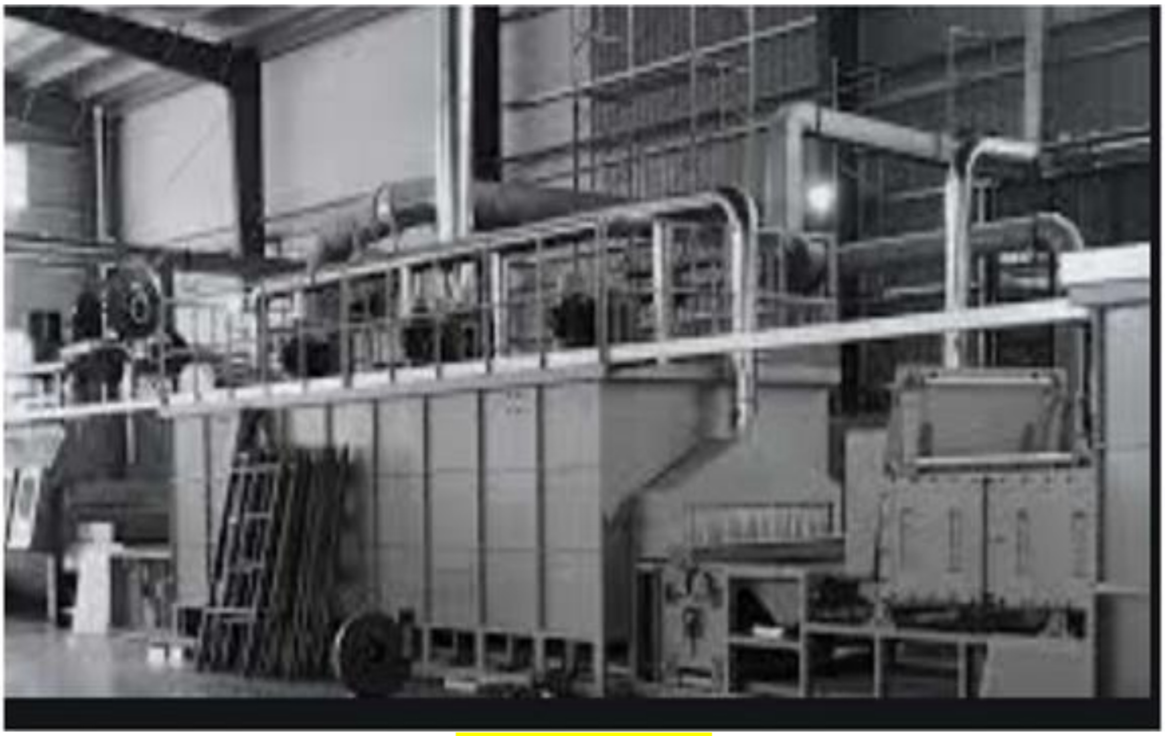
Utilities Electricity or PNG

Quality control

1.Measure the weight loss before and after cleaning. When the weight loss approaches zero, one can assume the surface is clean.
2.Ultra violet (UV) lamp test is suitable for internal and external surfaces. Most organic compounds will glow under UV light and indicate incomplete cleaning.
3.Wipe the surface of aluminum with white paper. Any contamination on the surface of aluminum would stain the white paper.
4.A coupon wettability test would indicate proper flux retention and distribution

Aqueous degreaser

Aqueous Degreaser will chemically remove the lubricating oils present on the heat exchanger from child parts or as a core. The assembled and fixtured product will be placed on the aqueous conveyor for processing. The aqueous degreaser will typically operate at 100 – 300°C to vaporize the oils. It consists of multiple zones where chemically concentrated alkaline solutions are sprayed at different temperatures.



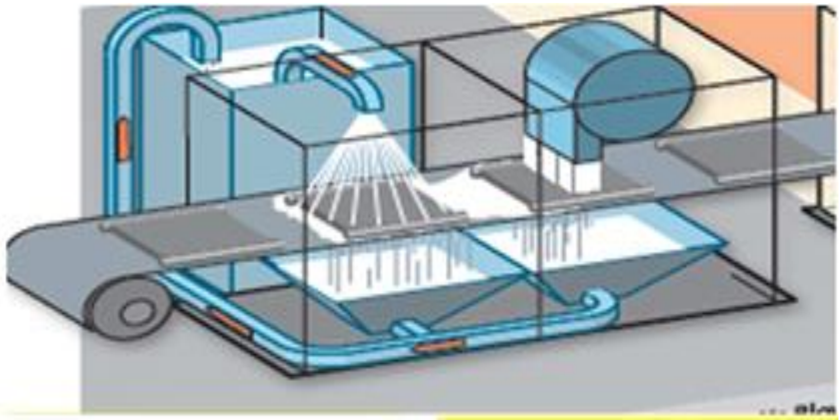
Industrial CAB Furnace

2.6 Fluxing

Function (Role/objective)

There is a natural protective oxide film on all Al surfaces. Even though the oxide film is very thin (100 Angstroms or less for wrought Al products), it is extremely hard, tenacious and has a very high melting point. When an Al surface is scratched, the oxide reforms instantaneously - this is why Al is said to be self-healing. It is this oxide, which gives Al its excellent corrosion properties. This oxide film must be removed or displaced to allow brazing, hence a metallurgical bond to occur between the metal surfaces. Once molten, the role of the flux is then to dissolve the oxide film on the Al surfaces to be joined and prevent re-oxidation during brazing. The flux wets the Al surfaces and allows the filler metal to flow freely into the joints by capillary action. Upon cooling, the flux remains on the brazed component as a thin tightly adherent film, which need not be removed.
The objective of fluxing is therefore to apply a thin uniform layer on all active brazing surfaces. The flux should be applied as thinly as feasibly possible without sacrificing brazeability. And lastly, the flux should be applied consistently and reliably from component to component

What happen if Oxidation on the surface of the heat exchangers. Oxygen **we won't Flux** will react with the aluminum alloy and make the aluminium oxide, which will prevent the clad to flow and even as oxygen is catalyst for fire or burn parts can burn or not braze , or dull aesthetic appearance will happen. Which will not qualify the quality acceptance criteria.
Working method In its simplest form, a slurry is held in a reservoir tank and continuously agitated to prevent settling. The slurry is pumped, usually with air-diaphragm pumps to the flux slurry cabinet where the heat exchangers moving on a conveyor are sprayed with the slurry. After spraying, the excess flux slurry is blown off in a separate chamber with high volume air. The over spray and blown off slurry is recycled back to the reservoir tanks, again using airdiaphragm pumps.
Depending on the sophistication desired, a second flux spray chamber may be installed after the first chamber to deliver a higher concentration slurry to problem areas such as tube to header joints in condensers and radiators. This second spray chamber would have a separate flux delivery system and a separate reservoir tank to contain the higher concentration flux slurry.
The components of the flux delivery system including reservoir and agitators should all be constructed of stainless steel or chemically resistant plastics (nozzles for instance). There should be no mild steel or copper containing components - including brass or bronze - in contact with the flux slurry. The schematic below shows the components of a generic fluxing station:



General arrangement of wet fluxing process

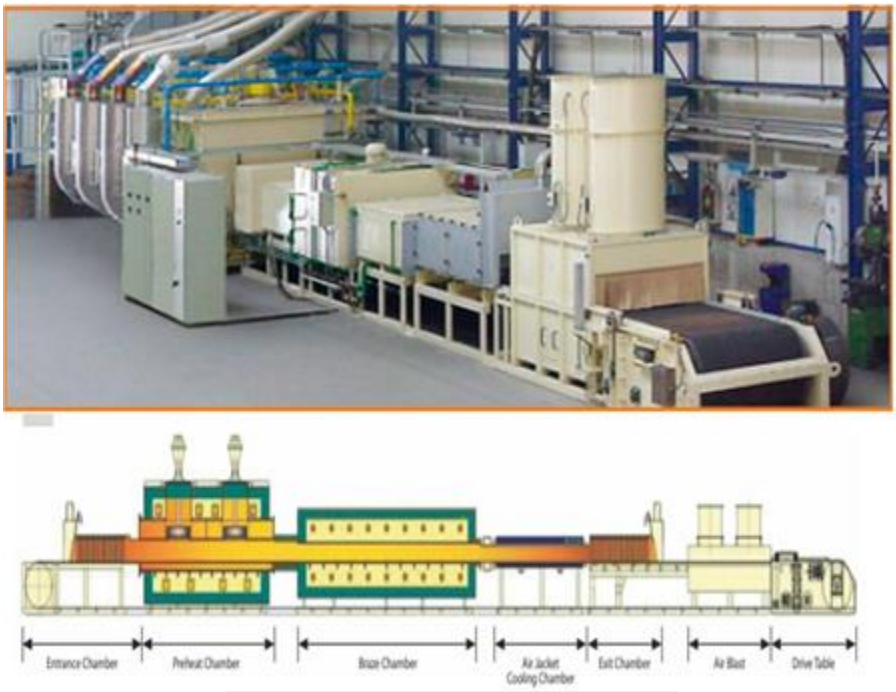
Utilities & Compressed air, Milarised water, Powder flux , Electricity **consumables**
Quality control Normally in fluxing process there are many controls which are mandatory to control but out of the all below are the most important and compulsory quality control 1. DM water quality (PH, TDS and conductivity)
2. Flux and water slurry concentration
3. Uniformity and homogeneity of flux application on parts
4. No access flux in parts
5. Deformation or visual defect in parts.

2.7 Dryer

Function The sole purpose of the dry-off section of the furnace is to **(Role/objecti** remove the water from the fluxing operation. The amount of **ve)** water carried into the dry-off oven depends on the flux slurry concentration - more dilute slurries carry in more water. One must also be aware of water on internal surfaces of heat exchangers such as inside radiator tubes. All

surfaces should be completely dry before entering the brazing furnace.
What happen Water Will enter inside the furnace along with the hex and as **if we won't** water contains oxygen it will destroy the inert atmosphere inside

Flux	the brazing zone, and increase the oxygen PPM.
Working method	Dryer is a simple chamber, where temperatures are maintained up to 300 deg Celsius, which will just evaporate the water from the wet flux. The target temperature should be about 200°C. This refers to the temperature that the part reaches and not the furnace atmosphere temperature. Note also that there is a potential for oxidation in a moist atmosphere over 300°C. The temperature of the heat exchanger should never approach 300°C in the dry off oven.
Utilities	Electricity or PNG



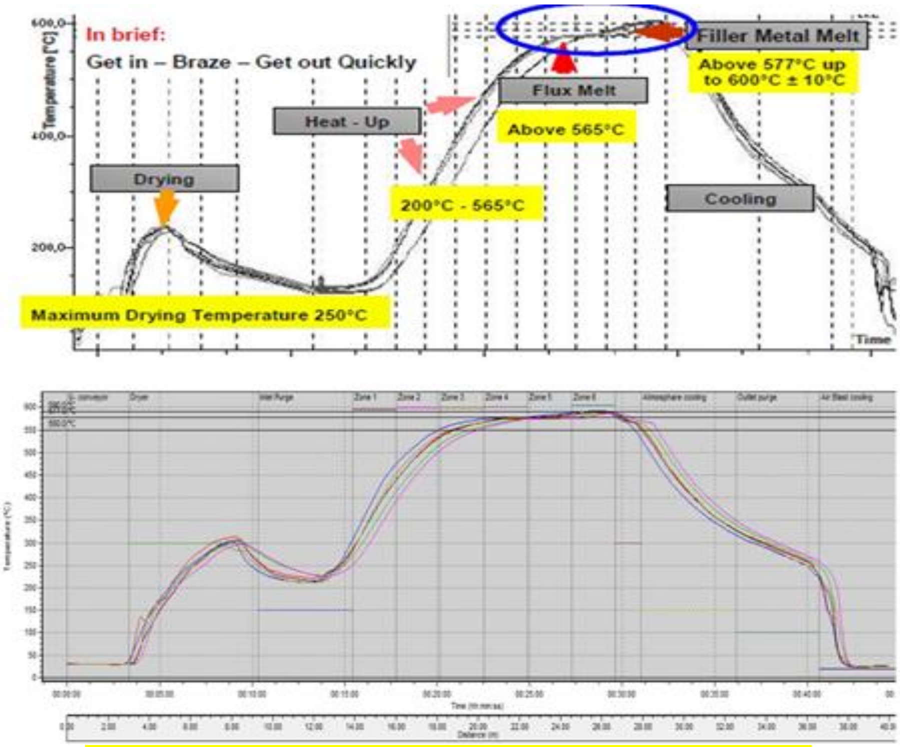
Furnace general arrangement and sub assy

2.8 Furnace
Function To provide the condition and environment to join(Braze) the **(Role/objecti** multiple contact points of the assembled HEX. **ve)**
Furnace O2 PPM<100
atmosphere Dew point <-40 deg celsius **Good** Inert gas -N2 (Nitrogen)
brazing Temperature deviation <3-5 deg celsius on part **conditions** Temperature homogeneity inside the muffle
Heating Rate A minimum average heating rate of 20°C/min up to the maximum brazing temperature is recommended. With very large heat exchangers such as charge air coolers, lower heating rates may be used, but with higher flux loadings. Once the flux starts to melt, it also begins to dry out. With slower heating rates, it is possible that the flux can be sufficiently dry as to lose its effectiveness when the filler metal starts to melt or before the maximum brazing temperature is reached.
In industry, heating rates up to 45°C/min in the range of 400°C to 600°C are very obvious. One could say that the faster the heating the better. However, temperature uniformity across the heat exchanger must be maintained especially when approaching the maximum brazing temperature and this becomes increasingly more difficult with fast heating rates.
Maximum For most alloy packages, the recommended maximum peak **Brazing** brazing temperature is anywhere from 595°C to 605°C and in **Temperature** most cases around 600°C.

Temperature Uniformity During heat up, there may be quite a variation in temperature across the heat exchanger. The variation will tighten as the maximum temperature is reached. At brazing temperature it is recommended that the variation should not exceed ± 5°C. This can be difficult to maintain when larger units are processed which have differing mass areas within the product.

Time at Temperature The brazed product should not remain at the maximum brazing temperature for any longer than 3 to 5 minutes. The reason is that a phenomena known as filler metal erosion begins to take place as soon as the filler metal becomes molten. And so the longer the filler metal remains molten, the more severe the erosion is.

The graph below shows an actual temperature profile for a heat exchanger brazed in a tunnel furnace. One characteristic feature of all temperature profiles is where the curve flattens out when approaching the maximum peak brazing temperature (area shown in blue circle). The plateau in the temperature profile is associated with the start of melting of the filler metal at 577°C, known as the latent heat of fusion. It is called latent heat because there is no temperature change when going from solid to liquid, only a phase change.



Thermal Uniformity survey Graph (Temperature distribution graph)

Above is the actual Datapaq(thermal profile measuring instrument) actual furnace temperature profile of the Charge air cooler.

Time at Temperature

Probe	Time Above 550.0°C (hh:mm:ss)	Time To Reach 550.0°C (hh:mm:ss)	Time Above 577.0°C (hh:mm:ss)	Time To Reach 577.0°C (hh:mm:ss)
#1 (°C)	00:10:10	00:21:00	00:04:00	00:26:00
#2 (°C)	00:09:35	00:21:55	00:02:40	00:27:30
#3 (°C)	00:10:35	00:20:10	00:05:05	00:24:40
#4 (°C)	00:10:00	00:21:05	00:05:30	00:24:35
#5 (°C)	00:09:35	00:22:20	00:02:20	00:28:10
#6 (°C)	00:10:30	00:20:45	00:04:35	00:25:35

Time and temperature table

The temperature and time study during the furnace CAB brazing. is shown above.

Utilities Electricity, PNG, Nitrogen

Quality control Most common controls are :- Visual defects,Tear down test, metallographic analysis , Leak test and Burst test

2.9 The Chemistry inside the Furnace/Brazing reaction

90°C – 150°C

- The moisture from the fluxing operation is driven off. This does not include the chemically bound water.

Reactions

290°C to 350°C

- Progressive release of chemically bound water in the flux (K2AlF5•H2O)

350°C - 565°C

- KAlF4 begins to vaporize and react with moisture.
- The more moisture there is to react, the more HF can be generated and the more the flux dries out as it is shifted away from its near eutectic composition.

565°C

- The flux starts to melt.

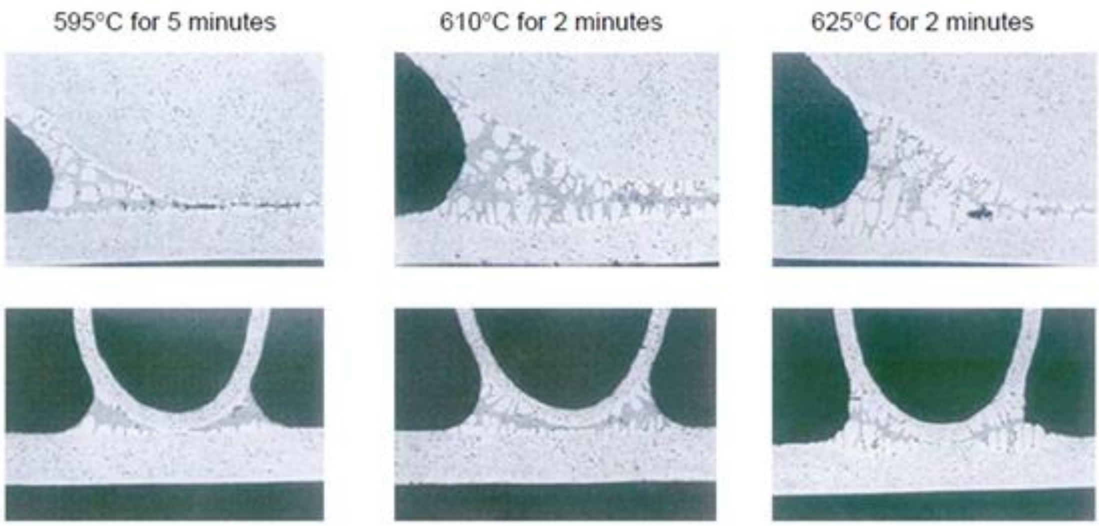
577°C - 600°C

- The filler metal starts to melt.
- Filler metal flows and forms fillets at joints

Cooling

- The filler metal solidifies.
- The flux solidifies and remains on the surface as a thin tightly adherent residue. The graph below shows a temperature profile for a brazed heat exchanger with the flux transformations. This provides an indication of approximately where in the brazing cycle these transformations occur:

2.10 Metallurgical formation at different temperature



CAB Brazing joints Metallographic analysis at different temperature

2.11 Chemistry and metallurgical reaction In Brazing

Before getting indulge to understand the thermochemistry of CAB, it is important to know about the materials involved in the CAB aluminium process.Below it is briefly explained about the materials and its application and characteristics.

Light weight and high thermal conductivity are two of the properties that make Al alloys ideal materials for heat transfer devices. Additionally, aluminum has the advantages of good formability, fairly good corrosion resistance and being Relatively cheap

Material involved in CAB process

AA designation	Alloy composition	Main characteristics	Applications, examples
Non-heat treatable alloys			
1xxx	Pure Al	High corrosion resistance, formability, electrical conductivity	Packaging, chemical equipment, electrical applications
3xxx	Al–Mn	High formability, corrosion resistance, medium strength	Heat exchangers, cooking utensils, chemical equipment
4xxx	Al–Si	High fluidity, medium strength	Casting, metal joining
5xxx	Al–Mg	Excellent corrosion resistance, toughness, moderate strength	Building and construction, automotive, cryogenic, marine
Heat treatable alloys			
2xxx	Al–Cu	High strength at elevated temperatures	Aircraft and truck bodies
6xxx	Al–Mg–Si	High corrosion resistance, excellent extrudability, moderate strength	Architecture, structural members, marine, truck frames, pipelines
7xxx	Al–Zn–Mg	Very high strength, some alloys have especially high toughness	Aircraft industry

Note: AA, Aluminum Association.

2.12 Chemistry in Flux (NOCOLOK)

<u>Composition</u>

NOCOLOK Flux is a mixture of potassium fluoroaluminate:

- $KAlF_4$ (70-80%)
- $K_2AlF_5 \cdot H_2O$ and K_2AlF_5 (20-30%)

K_2AlF_5 exists in different crystallographic forms:

- $K_2AlF_5 \cdot H_2O$
- K_2AlF_5 (phase I or α-phase)
- K_2AlF_5 (phase II or β-phase)

The ratio of the various crystallographic forms of K_2AlF_5 depends on the drying conditions during flux production. It is worthwhile noting that in a flux slurry most of the K_2AlF_5 is present as $K_2AlF_5 \cdot H_2O$.

During brazing the flux undergoes physico-chemical transformations

2.13 Characteristics

-Melting point range is 565°C to 572°C.

o This is below the melting point of filler metal (577°C)

- Particle size distribution – slurry grade (NOCOLOK® Flux)

o X50: 2 – 6 µm. This provides for good slurry characteristics while minimizing dust formation during handling.

- Particle size distribution – electrostatic application (NOCOLOK Flux Drystatic)

o X50: 3.5 – 25 µm. This provides for good fluidization and transport properties which are required when using electrostatic application equipment. The fraction of smaller particles provides for good flux adhesion on the heat exchanger.

- Non-hygroscopic

1. The only reaction of NOCOLOK® Flux with moisture is the re-hydration of phase I K_2AlF_5 to $K_2AlF_5 \cdot H_2O$. In the drying step of the NOCOLOK® Flux production, most of the $K_2AlF_5 \cdot H_2O$ is converted into K_2AlF_5 phase II. K_2AlF_5 phase II does not pick up water molecules from air and will (under these conditions) not transform to K_2AlF_5. Traces of phase I K_2AlF_5 in the flux most likely re-hydrate within six months after production. The total difference of losson-heating analysis related to the re-hydration of phase I K_2AlF_5 after this period is on average 0.5% without affecting the visible material appearance. As far as we know, there is no change in any chemical or physical flux characteristic related to this effect.

ISSN No:-2456-2165

2. Physical adsorption of moisture under humid conditions is an absolutely normal physical effect for a powder with large surface area. The flux has a very low water solubility and it will not liquefy in air by attracting humidity. NOCOLOK® Flux does not react with moisture and is not hygroscopic.
3. Since the flux is non-hygroscopic, it has an indefinite shelf life.

-Non-corrosive

- The flux does not react with aluminum whether in its solid or molten state. It only reacts with the oxide on aluminum and only does so when the flux is at least partially molten.

-Low water solubility.

- The flux is very slightly soluble in water where the solubility is in the range of 1.5 – 4.5 g/m2. There is no chemical reaction with water in solution. The slurry life is therefore theoretically indefinite.

- Flux residues

- The flux residues are non-corrosive and there is no interaction with coolants, refrigerants, oils and lubricants. Consequently, there is no need for flux residue removal.

Flux Transformation:-

By seeing below flow diagram of reactions, it could be easier to understand the chemical reactivity during the Brazing process:-

Flux is a mixture of potassium fluoroaluminate. It consists mainly of potassium tetra-fluoroaluminate ($KAlF_4$), and also contains potassium pentafluoroaluminate (K_2AlF_5). K_2AlF_5 exists in different modifications: potassium penta-fluoroaluminate hydrate ($K_2AlF_5 \cdot H_2O$), and hydrate-free (K_2AlF_5).

During the brazing process, the material undergoes essential physico-chemical alterations. While the chief component, $KAlF_4$, is simply heated up, the compound $K_2AlF_5 \cdot H_2O$ begins to lose its crystal water from 90°C (195°F) on. When the temperature is further increased within the ranges of 90° - 150°C (195°F - 302°F), and 290°C - 330°C (554°F - 626°F), two different crystallographic (structural) modifications of K_2AlF_5 are formatted.

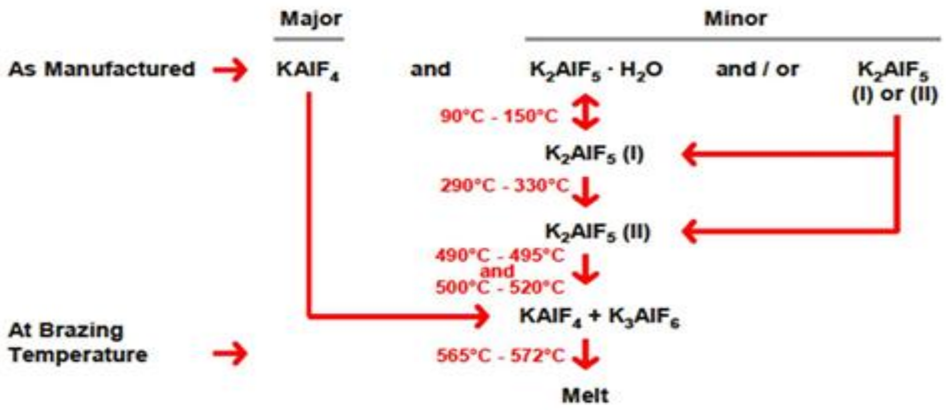
When the furnace temperature is raised above 490°C (914°F), K_2AlF_5 begins to react chemically. According to the equation:

$$2 \quad K_2AlF_5 \rightarrow KAlF_4 + K_3AlF_6$$

These flux fumes contain fluorides and have the potential to react with the furnace atmosphere, especially moisture, to form hydrogen fluoride according to the equation:

$$3 \quad KAlF_4 + 3\,H_2O \rightarrow K_3AlF_6 + Al_2O_3 + 6\,HF$$

The schematic below illustrates the transformations that occur as the flux is heated to brazing temperature. Note that these phases are unstable outside the furnace atmosphere.



III. OUTCOME OF REVIEW

In the era of dynamic changes in technology, marketplace, economy, political situation and global business environment, it is very essential to have the progressive design and continuous improvement in each process to meet the market demand as well as the conditional requirement of the situations.

It is clearly seen that automotive industries are expanding year by year as purchasing power of the people around the world is increasing. Specifically the developing countries are more significantly becoming the big market of the auto vehicle Like China and India. The scope of the market expansion is huge as in the USA per 1000 people 863 and in INDIA it is just 22. Therefore in coming years it is very likely to have the exponential growth in the automotive market in India and for meeting the customer demand it is very obvious that we will required the high efficient process, low cost solutions, Technological solution for production enhancement..etc

From the Literature review following points are concluded:-

1. CAB is the very essential process for HEX manufacturing.
2. The technology involved in CAB brazing is based on thermo physical reaction.
3. Temperature and time is the key for the CAB brazing process.
4. Flux is the key for the CAB Brazing
5. Inert gas is necessary for maintaining the atmosphere inside the furnace. Nitrogen is the most common inert gas which is being used in Furnace.
6. Composition of the material of aluminum alloy is important for the brazing and its qualitative output.
7. Several processes involved in CAB are equally important and hold similar importance.

IV. ANALYSIS

Process / Utilities	ELC	PNG	DMW	N2	CA
Thermal Degreaser	x	x			
Fluxer	x		x		x
Dryer	x	x			
Brazing	x	x		x	

Utilities vs process Matrix

4.1 Study of the electricity utilisation in different load condition:-

SR NO/ Shift Hours	TARGET TIME PERIOD (24h)	Electric Power Unit (KWh)											
		05.08.2019	Difference	06.08.2019	Difference	07.08.2019	Difference	08.08.2019	Difference	09.08.2019	Difference	10.08.2019	Difference
1	7:00	96195.1		96270	3.2	96346.4	3.6	96423.1	3.4	96498	3.9	96574.1	3.8
2	8:00	96198.1	3	96273.2	3.2	96349.5	3.1	96426.4	3.3	96502	4	96577.3	3.2
3	9:00	96201.2	3.1	96276.3	3.1	96352.6	3.1	96429.6	3.2	96505.5	3.5	96580.6	3.3
4	10:00	96204.3	3.1	96279.5	3.2	96355.7	3.1	APU QRQ C		96508.8	3.3	96583.7	3.1
5	11:00	96207.6	3.3	96282.6	3.1	96358.8	3.1	96435.8	6.2	96512.2	3.4	96587	3.3
6	12:00	96211	3.4	96285.7	3.1	96362	3.2	96438.9	3.1	96515.5	3.3	96590.6	3.6
7	13:00	96214.3	3.3	96289	3.3	96365.2	3.2	96442.2	3.3	96518.8	3.3	96594.2	3.6
8	14:00	96217.5	3.2	96292.2	3.2	96368.5	3.3	96445.5	3.3	96522	3.2	96597.8	3.6
9	15:00	96220.5	3	96295.3	3.1	96371.6	3.1	96448.6	3.1	96525.2	3.2	96601.2	3.4
10	16:00	96223.7	3.2	96298.4	3.1	96374.8	3.2	96451.6	3	96528.4	3.2	96604.6	3.4
11	17:00	96226.9	3.2	96301.7	3.3	96378	3.2	96454.9	3.3	96532.0	3.6	96607.8	3.2
12	18:00	96230.0	3.1	96305.1	3.4	96381.3	3.3	96458.2	3.3	96534.9	2.9	96611.0	3.2
13	19:00	96233.2	3.2	96308.1	3	96384.3	3	96461.4	3.2	96538.1	3.2	96614.2	3.2
14	20:00	96236.4	3.2	96311.2	3.1	96387.6	3.3	96464.7	3.3	96541.5	3.4	96617.7	3.5
15	21:00	96239.5	3.1	96314.4	3.2	96390.9	3.3	96468.0	3.3	96544.6	3.1	96620.8	3.1
16	22:00	96242.7	3.2	96317.6	3.2	96394.2	3.3	96471.4	3.4	96547.9	3.3	96624.1	3.3
17	23:00	96245.8	3.1	96320.8	3.2			96474.9	3.5	96551.1	3.2		2.8

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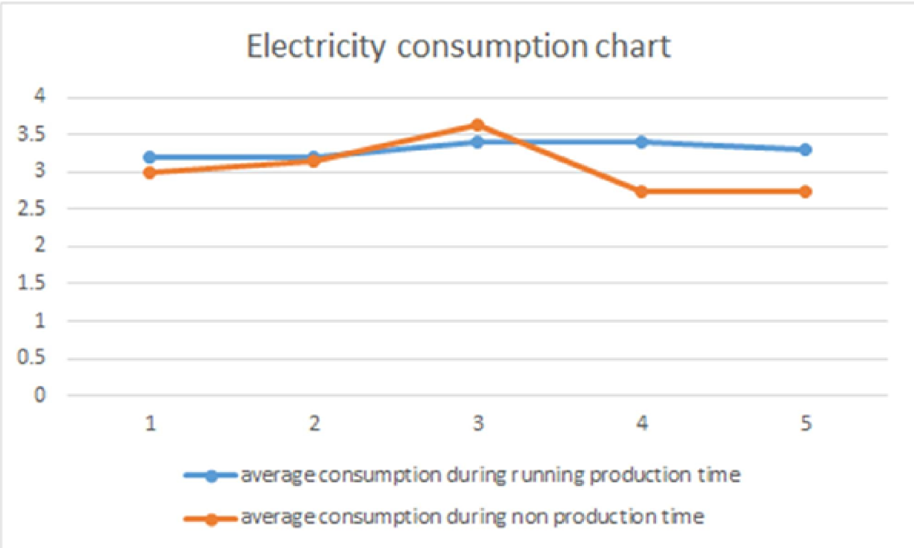
18	0:00	96248.8	3	96323.8	3	96400.3	6.1	96477.4	2.5	96553.6	2.5	96629.7	2.8
19	1:00	96251.7	2.9	96327.1	3.3	96403.5	3.2	96478.8	1.4	96555.2	1.6	96631.2	1.5
20	2:00	96254.7	3	96330.3	3.2	96406.8	3.3	96480.4	1.6	96556.5	1.3	96632.7	1.5
21	3:00	96258	3.3	96334	3.7	96410	3.2	96481.9	1.5	96558	1.5	96634.2	1.5
22	4:00	96260.6	2.6	96337.1	3.1	96413.2	3.2	96485.1	3.2	96561.2	3.2	96637.5	3.3
23	5:00	96263.8	3.2	96339.7	2.6	96416.4	3.2	96490	4.9	96566.3	5.1	96642.3	4.8
24	6:00	96266.8	3	96342.8	3.1	96419.7	3.3	96494.1	4.1	96570.3	4	96646.6	4.3
		71.7		72.8		73.3		71		72.3			
			3.12		3.17		3.33		3.23		3.14		3.15
average consumption during running production time			3.2		3.2		3.4		3.4		3.3		3.3
average consumption during non production time			3.00		3.14		3.64		2.74		2.74		2.81

Actual Hourly electricity data collected from XXX Industrial CAB Furnace for different load condition

After study of the data it concludes that during the full load condition of the furnace consumption of electricity is more than in idle condition however furnace is running with the same load of electricity 24/7.



By this data it is very clear that the there is scope of optimizing the temperature specification in furnace which can help us to reduce the energy usages in different load conditions.

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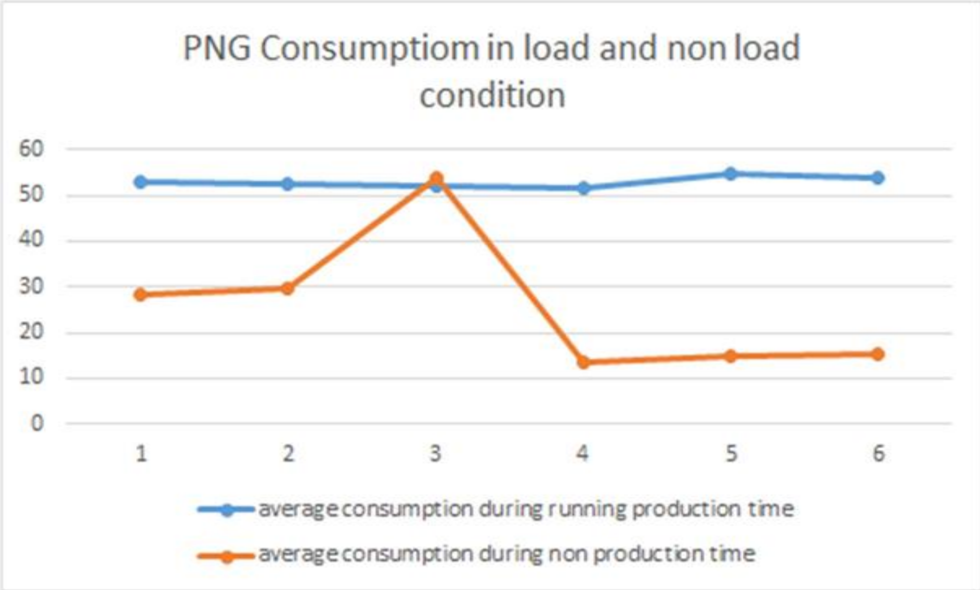
4.2 Study of the PNG consumption in different load condition:-

SR NO / Shift Hours	TARGET TIME PERIOD (24 h)	PNG Readings (M3)															Persur e:-	12.5		
		05.08.2019	Difference	Consumption Calculation	MMBTU(Metric Million British Thermal Unit) 1M3= 0.0353	06.08.2019	Difference	Consumption Calculation	07.08.2019	Difference	Consumption Calculation	08.08.2019	Difference	Consumption Calculation	09.08.2019	Difference	Consumption Calculation	10.08.2019	Difference	Consumption Calculation
1	7:00					101367.5	6.03	75.375	101456.3	5.86	73.25	101555.2	3.91	48.875	101632.8	3.82	47.75	101710.5	2.9	36.25
2	8:00					101372.1	4.6	57.5	101460.6	4.3	53.75	101559.8	4.6	57.5	101637.6	4.8	60	101715.1	4.6	57.5
3	9:00	101288.9				101377.1	5	62.5	101466.1	5.5	68.75	101564.4	4.6	57.5	101642.1	4.5	56.25	101719.3	4.2	52.5
4	10:00	101293.3	4.4	55	1.94			0	APU QRQC		0	APU QRQC		0	APU QRQC	APU QRQC		101723.7	4.4	55
5	11:00	101297.6	4.3	53.75	1.90	101386.4	9.3	116.25	Breakdown		0	101574.1	9.7	121.25	101651	8.9	111.25	101728.1	8.8	110
6	12:00	101301.6	4	50	1.77	101390.9	4.5	56.25	101479.6	13.5	168.75	101578.1	4	50	101654.6	3.6	45	101732.4	4.3	53.75
7	13:00	101305.5	3.9	48.75	1.72	101394.7	3.8	47.5	101483.5	3.9	48.75	101581.9	3.8	47.5	101658.9	4.3	53.75	101736.6	4.2	52.5
8	14:00	101309.6	4.1	51.25	1.81	101399.1	4.4	55	101487.5	4	50	101586.6	4.7	58.75	101663.7	4.8	60	101741	4.4	55
9	15:00	101314.4	4.8	60	2.12	101403.3	4.2	52.5	101492.1	4.6	57.5	101591	4.4	55	101668.2	4.5	56.25	101744.8	3.8	47.5
10	16:00	10131	3.9	48.75	1.72	10140	4.1	51.25	10149	3.5	43.75	10159	3.7	46.25	10167	3.7	46.25	10174	3.8	47.5
		8.3				7.4			5.6			4.7			1.9			8.6		
11	17:00	101322.5	4.2	52.5	1.85	101411	3.6	45	101499.5	3.9	48.75	101598.7	4	50	101676.3	4.4	55	101753.5	4.9	61.25
12	18:00	101326.6	4.1	51.25	1.81	101415.7	4.7	58.75	101504.2	4.7	58.75	101602.5	3.8	47.5	101680.6	4.3	53.75	101757.6	4.1	51.25
13	19:00	10133	4.5	56.25	1.99	10141	4.1	51.25	10150	4.2	52.5	10160	3.8	47.5	10168	4.3	53.75	10176	4.0	50

		1.1				9.8			8.4			6.3			4.9			1.6		
14	20:00	101335.1	4	50	1.77	101424.8	5	62.5	101512.1	3.7	46.25	101610.2	3.9	48.75	101688.7	3.8	47.5	101765.4	3.8	47.5
15	21:00	101339.3	4.2	52.5	1.85	101427.8	3	37.5	101516.4	4.3	53.75	101614.1	3.9	48.75	101692.5	3.8	47.5	101769.2	3.8	47.5
16	22:00	101344.0	4.7	58.75	2.07	101431.9	4.1	51.25	101521.1	4.7	58.75	101617.6	3.5	43.75	101696.4	3.9	48.75	101773.8	4.6	57.5
17	23:00	101448	4.0	50	1.77	101436	4.1	51.25			0	101621.5	3.9	48.75		2.8	34.5625		2.6	32.5
18	0:00	101550.35	2.35	29.375	1.04	101439.11	3.11	38.875	101528.76	7.66	95.75	101622.73	1.23	15.375	101701.93	2.8	34.5625	101779	2.6	32.5
19	1:00	101552.59	2.24	28	0.99	101441.46	2.35	29.375	101532.48	3.72	46.5	101623.5	0.77	9.625	101702.79	0.86	10.75	101779.89	0.89	11.125
20	2:00	101554.83	2.24	28	0.99	101443.66	2.2	27.5	101536.02	3.54	44.25	101624.38	0.88	11	101703.54	0.75	9.375	101780.64	0.75	9.375
21	3:00	101557	2.17	27.125	0.96	101445.96	2.3	28.75	101539.77	3.75	46.875	101625.27	0.89	11.125	101704.37	0.83	10.375	101781.57	0.93	11.625
22	4:00	101559.3	2.3	28.75	1.01	101448.25	2.29	28.625	101543.71	3.94	49.25	101626.3	1.03	12.875	101705.22	0.85	10.625	101782.45	0.88	11
23	5:00	101561.47	2.17	27.125	0.96	101450.44	2.19	27.375	101547.45	3.74	46.75	101627.64	1.34	16.75	101706.43	1.21	15.125	101783.74	1.29	16.125
24	6:00	101563.87	2.4	30	1.06	101452.66	2.22	27.75	101551.29	3.84	48	101628.98	1.34	16.75	101707.6	1.17	14.625	101785.04	1.3	16.25
		222975.21	74.97	937.125	33.08	233287.04	91.19	1139.875		100.85	1260.625		77.69	971.125		78.62	982.75		81.84	1023
average consumption during running production time				52.8				52.6			52.0			51.6			54.8			53.8
average consumption during nonproduction time				28.34				29.75			53.91			13.36			15.06			15.43

Actual Hourly PNG data collected from XXX Industrial CAB Furnace for different load condition



The above data indicates that the scope of improvement and standardization is huge. Because the consumption rate at load condition VS non load condition having 50% difference in consumptions.

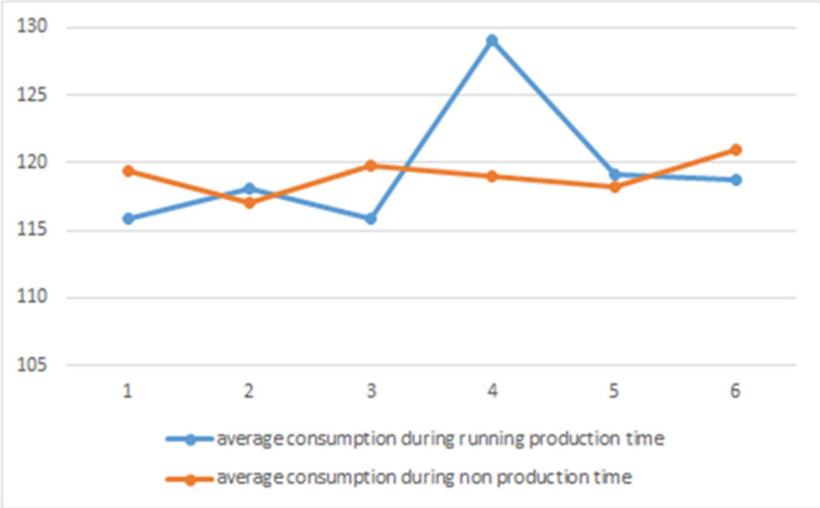
Therefore the standardization can be done here to use the PNG at optimum level at different load conditions in CAB furnace.

4.3 Study of the N2 consumption in different load condition

SR NO/ Shift Hour s	**TAR GET TIME PERI OD (24h)**	**NITROGEN Readings (NM3)**											
		05.08. 2019	**Differ ence**	**06.08. 2019**	**Differ ence**	07.08. 2019	**Differ ence**	08.08. 2019	**Differ ence**	09.08. 2019	**Differ ence**	10.08. 2019	**Differ ence**
1	7:00	73681 1.5		73960 9.2	122.4	74244 6.5	125.9	74527 0.7	129.2	74815 4.4	128.4	75101 7.2	127.6
2	8:00	73691 9.5	108	73972 8	118.8	74256 4.4	117.9	74539 2.6	121.9	74828 3.3	128.9	75113 6.8	119.6
3	9:00	73702 8.6	109.1	73984 7.8	119.8	74268 0	115.6	74551 6.2	123.6	74839 4.4	111.1	75125 4.3	117.5
4	10:00	73713 7.6	109	73996 6.9	119.1	74279 4.6	114.6	APU QRQ C		74851 1.4	117	75137 1.4	117.1
5	11:00	73725 5.8	118.2	74008 5.1	118.2	74291 5.3	120.7	74575 8.5	242.3	74863 9.3	127.9	75149 0.8	119.4
6	12:00	73736 4.5	108.7	74020 5.5	120.4	74303 2.1	116.8	74587 8.7	120.2	74875 1.1	111.8	75160 7.2	116.4
7	13:00	73747 3.5	109	74032 5.4	119.9	74314 4.9	112.8	74599 9.3	120.6	74887 2.2	121.1	75172 4.3	117.1
8	14:00	73758 3.6	110.1	74044 3.2	117.8	74326 3.1	118.2	74612 1.7	122.4	74899 1.9	119.7	75184 3.7	119.4
9	15:00	73769 3.5	109.9	74055 8.6	115.4	74337 9.8	116.7	74624 1.8	120.1	74911 2.5	120.6	75195 8.1	114.4

10	16:00	737806.6	113.1	740674.2	115.6	743493.9	114.1	746356.5	114.7	749226.5	114	752077.1	119
11	17:00	737928.8	122.2	740794.8	120.6	743605	111.1	746476.5	120	749362.8	136.3	752191.7	114.6
12	18:00	738047.7	118.9	740919.1	124.3	743725	120	746596.4	119.9	749466.7	103.9	752309.5	117.8
13	19:00	738169.4	121.7	741028.8	109.7	743840.3	115.3	746715.7	119.3	749585.9	119.2	752428	118.5
14	20:00	738291.9	122.5	741147.1	118.3	743956.1	115.8	746835.1	119.4	749708.7	122.8	752559.4	131.4
15	21:00	738408.9	117	741264.4	117.3	744071.3	115.2	746954.1	119	749824.2	115.5	752676.9	117.5
16	22:00	738530.4	121.5	741384.5	120.1	744192	120.7	747069.1	115	749938.4	114.2	752797.8	120.9
17	23:00	738650.8	120.4	741501	116.5		110.9	747193.1	124	750061.7	123.3		118.8
18	0:00	738771.4	120.6	741612.8	111.8	744413.8	110.9	747308.8	115.7	750181.2	119.5	753035.4	118.8
19	1:00	738889.1	117.7	741733.3	120.5	744531.9	118.1	747426.3	117.5	750310.4	129.2	753157.2	121.8
20	2:00	739007.9	118.8	741849.1	115.8	744654.3	122.4	747546.9	120.6	750414.4	104	753278.2	121
21	3:00	739126.4	118.5	741968.8	119.7	744776.3	122	747666.7	119.8	750532.6	118.2	753399.4	121.2
22	4:00	739243	116.6	742085.2	116.4	744897.8	121.5	747787	120.3	750651.6	119	753520.8	121.4
23	5:00	739368.3	125.3	742202.2	117	745018.2	120.4	747906.2	119.2	750772.1	120.5	753642.1	121.3
24	6:00	739486.8	118.5	742320.6	118.4	745141.5	123.3	748026	119.8	750889.6	117.5	753763.7	121.6
average consumption during running production time			115.9		118.1		115.9		129.0		119.1		118.7
average consumption during non production time			119.43		117.09		119.80		118.99		118.27		121.01

Actual Hourly Nitrogen data collected from XXX Industrial CAB Furnace for different load condition



After studying the collected data and reviewing the interaction graph it is not very clear what could be the optimum rate of consumption and utilisation of the N2 in different load conditions. However with this data the interaction correlation could not be established .

V. DATA SUMMARY

	Nitrogen consumption (m3/h)			PNG consumption (SCM)			Electricity consumption (KWH)		
Date	Average consumption during running production time	Average consumption during non production time		Average consumption during running production time	Average consumption during non production time		Average consumption during running production time	Average consumption during non production time	
08/05/2019	115.9	119.43	No change	52.8	28.34	TDC	3.2	3.00	TDC
08/06/2019	118.1	117.09	GC	52.6	29.75	TDC+GC	3.2	3.14	TDC+GC
08/07/2019	115.9	119.80	GC	52.0	53.91	No change	3.4	3.64	No change
08/08/2019	129.0	118.99	GC	51.6	13.36	TDC+GC +RC	3.4	2.74	TDC+GC +RC
08/09/2019	119.1	118.27	GC	54.8	15.06	TDC+GC +RC	3.3	2.74	TDC+GC +RC
08/10/2019	118.7	121.01	GC	54.8	15.06	TDC+GC +RC	3.3	2.81	TDC+GC +RC
	119.4	119.10		53.1	25.91		3.3	3.01	
	UOM	**Set value**	**Nitrogen**	**Value**	**% reduction**	**Legend**	**Abbreviation**		
	m3/h	110	No change	119.4		TDC	Thermal degreaser and Dryer closed		

	m3/h	110	GC	119.10	0.29%	GC	Gate started closing		0.13951 69579
	UOM	**Set value**	**PNG**	**Value**	**% reductio n**	RC	Recipe calendar		
	SCM		No change	53.1					
	SCM		TDC+GC	29.75	43.97%				
	SCM		TDC+GC +RC	14.49	72.71%				
	UOM	**Set value**	**Electrici ty**	**Value**	**% reductio n**				
	KWH		No	3.3					
			change						
	KWH		TDC+GC	3.14	4.85%				
	KWH		TDC+GC +RC	2.74	16.97%				

All utilities data summary for different conditions

Abbreviations

GC:- Gate closed, DC:- Thermal degreaser close, RC:- Recirculation FAN Close

VI. ANALYSIS AND CONCLUSION

Current Scenario When 2 Shift Production and 1 shift no production			
	Nitrogen	PNG	Electricity
Per day consumption Without any change	2866.797802	1274.4	792
Per day Consumption with TDC+GC	2863.979487	1087.6	779.2
Per day consumption with TDC+GC+RC	2863.979487	965.52	747.2
Consumption % Saving/ day	0.10%	24.24%	5.66%

Utilities pattern at different condition and 1 shift idle load pattern.

When all Three Shift Will run in below pattern			
	Nitrogen	PNG	Electricity
Per day consumption Without any change	2866.797802	1274.4	792
Per day Consumption with TDC+GC	2858.342857	714	753.6
Per day consumption with TDC+GC+RC	2858.342857	347.76	657.6

Utilities pattern at different condition at 100% utilization load pattern.

Hourly reduction in consumables by different actions						
UOM	**Set value**	**Nitrogen**	**Value**	**% reduction**	**Legend**	**Abbreviation**
m3/h	110	No change	119.4		TDC	Thermal degreaser and Dryer closed
m3/h	110	GC	119.10	0.29%	GC	Gate started closing

UOM	Set value	PNG	Value	% reduction	RC	Recipe calendar
SCM		No change	53.1			
SCM		TDC+GC	29.75	43.97%		
SCM		TDC+GC+RC	14.49	72.71%		
UOM	**Set value**	**Electricity**	**Value**	**% reduction**		
KWH		No change	3.3			
KWH		TDC+GC	3.14	4.85%		
KWH		TDC+GC+RC	2.74	16.97%		

Utilities Optimization with different actions.

5.2 Conclusion

By analyzing the data and graphs it is very clear that there are multiple scope of improving the efficiency of the process by reducing the utilities consumption and energy utilization reduction.

The technical data says that the consumption of the utilities can be different in load condition and non-load condition which can have correlation between the different parameters and the programme can be developed with the simulated DOE condition and factor analysis.

5.3 Recommendations Improvement in industry

Immediate implementation Actions

1. In no load condition all gates are closed to avoid the loss of energy.
2. The auto compress air closure during the gap in loading or in changeover.
3. N2 flow rate can be immediately reduced by 50% in no load condition.

Future Deliverable Actions and recommendation

1. The HEX size and weight wise auto adjustment of the recipe and specification to be introduced to optimise and minimise the usages of utilities.
2. Based on the study and data the efficiency depends on the escape outlet prevention for eneary, therefore the all escape point to be designed in such a way that can be adjustable according to the product size and shape. It should not be universal for multiple product CAB Furnace.

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