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EE11704011-Waste Heat Recovery on Hot Dip Galvanizing Furnace (Design & Manufacturing)

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Abstract

Abstract- Energy is very precious and wastage is unaffordable. Energy sources are very much limited on our planet and hence we must do every effort to save or recover energy going waste without use. In Hot Dip Galvanizing Plant lot of heat energy is going in to atmosphere as a waste along with flue gases. One can recover this and can reuse it to reduce fuel consumption and to improve quality of Galvanizing in same plant. Calculation of Potential of this waste energy by Flue Gas Analysis and Combustion Calculations is very important to design a Heat Exchanger. Most important is to select the location for of recovered energy. In Waste Heat Recovery (WHR) optimum Thermal Design of recovery unit and reuse unit is very important. A round around coil technique is very much suitable for such kind of Medium Temperature Heat Recovery. To make unit compact Finned Tube or Plate Type heat exchangers are designed for recovery and reuse units. Pressure drop calculations for flue gas side are very high importance while designing WHR Units (WHRU) as performance of Hot Dip Galvanizing Furnace should not affected by WHRU. Manufacturing of WHRU also plays important role in final performance, Sound Engineering Practices (SEP) are required during manufacturing. Validation of design is done by analyzing results of WHRU after successful commissioning.

Keywords:_Combustion Calculations, Thermal Design, WHRU, Compact Heat Exchangers, Finned Tube Heat Exchangers, Flue Gas Analysis, Heat Exchangers, Heat Duty_

1. Introduction

The majority of energy production from conventional and renewable resources are lost to the atmosphere due to onsite (equipment inefficiency and losses due to waste heat) and offsite (cable and transformers losses) losses, that sums to be around 66% loss in electricity value. Waste heat of different degrees could be found in final products of a certain process or as a by-product in industry such as the slag in steelmaking plants. Units or devices that could recover the waste heat and transform it into electricity or any other useful energy are called Waste Heat Recovery Units(**WHRUs)** or heat to power units.A WHRU is an energy **recovery heat** exchanger that recovers **heat** from hot streams with potential high energy content. There are many sources such as heat in flue gases; heat in vapor streams; convective and radiant heat that is lost from exterior of equipment; also in heat stored in products that leave the process and finally heat in gaseous and liquid effluents leaving the process. I have got an opportunity to design and develop a Waste Heat Recovery Unit for Valmont Structures.

Valmont Structures have a Hot Dip Galvanizing (HDG) tank having dimensions around 30m long, 4m wide and 5m deep is heated burning Propane to maintain desired temperature of molten zinc (450 to 460 ^{o}C). Furnace is present and hot flue gas from furnace passes around outside of galvanizing tank. Flue gas leaving the outer chamber of galvanizing tank to sack ranges from 350 to 500 ^{o}C. Before installation of WHRU, this gas was directly going to atmosphere causing thermal pollution as well as loss of valuable energy. The target were to reduce thermal pollution & reuse the waste energy again in the galvanizing process to reduce Fuel Consumption as well as to improve quality of galvanizing. There were four different locations were recovered energy can be used practically, first is for heating cleaning reagents, second is for heating pickling solutions, third is Flux tank heating and fourth is pre-heating of process material before going to hot dip galvanizing tank.

The most economical and efficient option found out of four was to reuse recovered heat for flux tank heating. Use of hot flux (Temperature around 65 ^{o}C) improves the quality and durability of galvanize coat. Further details will be discussed in detail in following pages.

2. Literature Review

Many references as follows were viewed during preparation of this paper to understand the HDG process. "Energy Performance Assessment for Equipment and Utility Systems" published by "Bureau of Energy Efficiency", Ministry of Power, Government of India(2015). Chapter 1 and 2 are useful for combustion calculations. I have referred this book for all basic and advanced combustion calculations , to find out Stoichiometric air requirement, Excess air requirement, Flue gas flow rate etc. This book have helped me for establishing flue gas composition.

"Energy Efficiency in Thermal Utilities" published by "Bureau of Energy Efficiency", Ministry of Power, Government of India (2015). Chapter 1 & 2 Fuels & Combustions and Boilers are useful in combustion calculations as well as detail analysis of fuel. This book have helped me in determining exact fuel ingredients and combustion products after burning of fuel. "Process and Design Notes on Hot Dip Galvanizing (2003)", Providing efficient heating systems in the galvanizing plant is essential to lowering operating costs. Efficient heating practices not only reduce the amount of fuel used in the galvanizing plant, but will also reduce maintenance costs as the need to replace process equipment decreases. Surface preparation tanks typically need to be heated to ensure effective cleaning action of the solution. This is most commonly achieved in galvanizing plants using steam coils constructed of highly corrosion-resistant materials. Overall galvanizing along with pre-treatments are explained briefly in this paper. Guidelines during design of heat exchanger for corrosive fluid and for corrosive atmosphere are provided in this paper."The Galvanizing Handbook – Surface Preparation (1996)". This handbook explains Hot-dip Galvanizing process and surface cleaning processes required. Effects of each surface cleaning process over final quality of Galvanizing is discussed in deep in this book and hence helpful to take decision about most important pre-treatment process and ultimately helpful in deciding effective and efficient use of waste heat during the pre-treatment process. "Stainless steel finned tube heat exchanger design for waste heat recovery from Journal of Energy in Southern Africa (2006)" explains Around the world the implementation of heat recovery systems play an increasingly important role in the engineering industry. Recovered energy is utilized in production plants and saves companies millions in expenses per year. Guidelines for high pressure, cross flow, stainless steel finned tube heat exchanger with a water side pressure rating of 2 MPa are helpful in design and construction of waste heat recovery unit which is mounted in between exhaust flue gas path. "The Basics of Hot Dip Galvanized Steel (2012)", This Guide is intended to keep readers abreast of current issues and developments in the field of galvanizing. The Galvanizers Association of Australia has made every effort to ensure that the information provided is accurate, and useful. This book provides valuable information regarding galvanizing and precautions and pre-treatments required before galvanizing. Galvanizing coating characteristics and factors affecting the coating are very well explained in this guide book. This book had helped me during selection of location for re-use of recovered heat and also in selection of MOC of flux tank heat exchanger."Thermodynamics -An Engineering Approach (2011)", This book is very helpful for doing combustion calculations, specifically chapter 15, Chemical Reactions gives detail idea about combustion calculations. "Heat and Mass Transfer (2016)", All thermal design is based on this book. Convection plays major role in heat transfer, this book explains all three modes, Conduction, Convection & radiation of heat transfer. I have refer this book for doing all thermal calculations. "ASME Boiler and Pressure Vessel Code Section VIII Div. 1" provides guide lines to for mechanical design of heat exchanger. Minimum tube thickness calculations, tube sheet thickness calculation, nozzle pipe thickness etc. are done by using formulae provided in this code.

There is very little information available on Waste Heat Recovery on HDG Plant. How to recover heat and where to use is question mark. Flux is very corrosive and hence material selection for flux tank Heat Exchanger is important task, another most important task is control logic, it is necessary to install WHRU without affecting the performance of existing furnace. This part is handled carefully in our work of design and manufacturing.

3. Work Carried Out &Equipment Set-Up

Design and Manufacturing of Waste Heat Recovery System For Hot Dip Galvanizing Plant.

Huge amount of heat energy go waste along with flue gases without any use. Study of Galvanizing Process for optimum and effective use of this wasted energy along with selection and design of medium temperature heat recovery technique, Thermal and Mechanical design of heat exchangers, development of control logic and safety interlocks, finally validation of results was the prime goal. In India very few people bothers about waste energy, almost all galvanizing plants installed before 2012 are wasting energy and need to install with WHRU. This paper will give better idea to achieve this goal and huge amount of energy will be saved and reused again.

The main objective is to propose and design effective and efficient WHR system to reduce energy waste.

1..Design& development of Waste Heat Recovery Unit (WHRU)

2. Development of Control Logic and safety interlocks for smooth operation (P & I Diagram).

3. Performance Testing and Validation of design.

There are total four locations were we can use recovered heat, the locations are 1. Degreasing Solutions 2.Pickling Tank 3.Flux Tank (Valmont have existing dedicated system for heating flux tank, but capacity of system is not sufficient. Another problem is frequent leakages in heat exchanger immersed in flux tank having MOC SS304) 4. Pre-heating the process material before galvanizing.

After deep study of Galvanizing Process it is clear that the most efficient and economical location is "Flux Tank Heating". Application of Flux at recommended temperature improves quality of galvanizing to a great extent. This WHR comes under "Medium Temperature Waste Heat Recovery", the distance between HRU and Flux tank where recovered heat is used is around 50 m and hence **Run Around Coil Exchanger** technique is used.Exchanger 1 (Finned Tube) is recovery exchanger and Exchanger 2 (Plain Tube) is reuse exchanger. Manufacturing and installation of both the heat exchangers is done by using standard engineering practices (SEP). After proper installation, insulation work is completed, proper insulation is very mush essential to improve the performance of WHRU.

Readings are recorded after continuous running of system for 48 hours from commissioning.

Hot Gas Side Heat Exchanger (Exchanger 1) :- Gas - Liquid Heat Exchanger, Liquid (re-circulated water) inside the tube and hot flue gas shall flow outside the tubes. To enhance heat transfer and to make heat exchanger compact, we will provide extended surfaces in form of round fins over tubes. Due to limited space available between stack and flue gas duct there is need to make equipment compact.

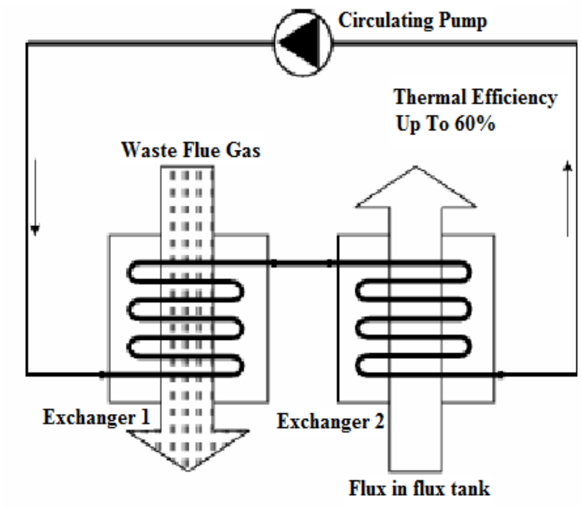

Fig. 1 Run Around Coil WHR Technique

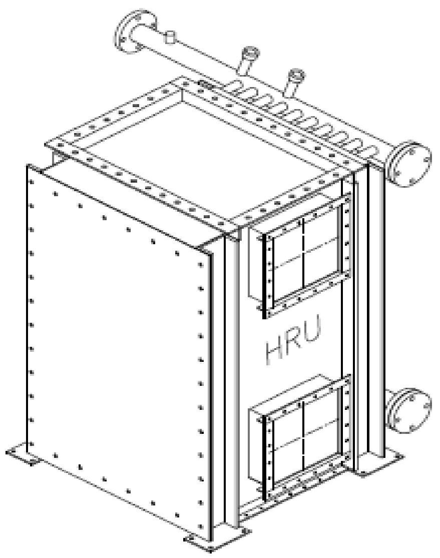

Fig. 2WHRU (Heat Exchanger 1)

Flux side Heat Exchanger (Exchanger 2) :- Liquid - Liquid Heat Exchanger, heat carrying liquid (re-circulated water) shall flow inside the tunes and corrosive flux shall be outside the tube. Being liquid - liquid exchanger we have decided to adopt bear tube design.

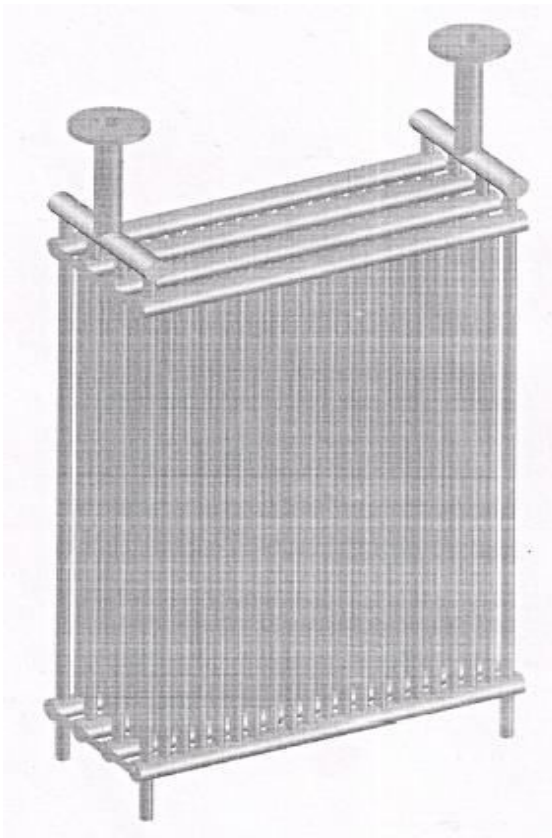

Fig. 3 View of Re-Use HEX (Heat Exchanger 2)

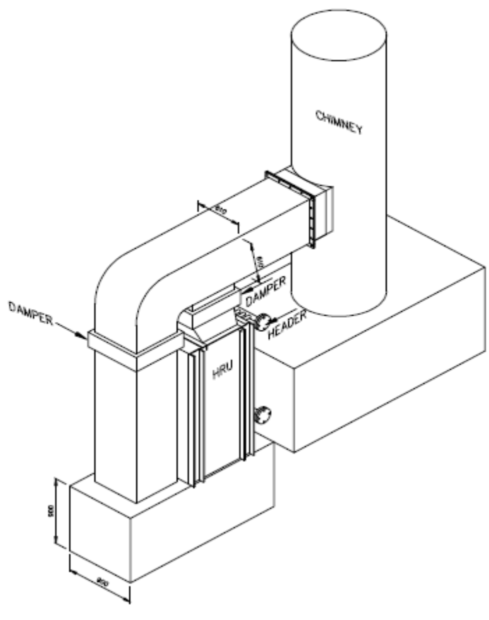

Fig. 4 Isometric View of WHRU

Galvanizing plant comes under dirty plant category as environment or atmospheric conditions around galvanizing process are not healthy and mostly corrosive gases are present in air. This corrosiveness of air affects selection of material for heat exchangers.

Even pre-treatment processes have very corrosive solutions in use like HCl, H_2SO_4, Flux etc. and Heat Exchangers required to transfer heat to these solutions are of special materials. Selection of material is very important task. The material selected for Heat

Exchanger 1 is SS 304 and that for Heat Exchanger 2 is Titanium.

Development of control logic and safety interlocks to ensure smooth, unhampered working of existing propane fired furnace as well as newly designed WHRU. Input parameters to design WHRU are freeze by analyzing flue gas and doing combustion calculations. Thermal and Mechanical Design of finned tube recovery heat exchanger and plain tube (Titanium tubes to withstand highly corrosive flux) heat exchanger to reuse recovered heat is carried out followed by preparation of manufacturing drawings and P & I Diagram.

Using the knowledge from literature review, we can know about the potential for waste heat recovery. Finding various opportunities to reuse recovered energy, selection of location to reuse, Thermal Design of WHRU, Mechanical check for safe thicknesses, development of control logic etc. is briefed about in the technical papers referred.

Following Methodology need to adopt while carrying out this work

1. Study of Hot Dip Galvanizing Process -Helps in defining various locations to re-use recovered energy and also Provides guidelines for Selection of most deserving location where effective and efficient use is possible
2. Flue Gas Analysis and Combustion Calculations- Flue gas analysis & Combustion Calculation provides Basic input data required for Thermal Design. It helps in calculating heat duty available with flue gas.
3. Development of Control Logic and Safety Interlocks- Essential for smooth and un interrupted operation of WHRU & Galvanizing Furnace Safety interlocks and also provides protection from abnormal conditions & prevents system failures.

4, Preparation of manufacturing drawings and QAP - Detail drawing of WHRU for better communication with shop floor.Quality is most essential and need to maintain, QAP provides guideline to achieve good quality.

5. Fabrication & NDT- Fabrication of equipment as per SEP and to ensure final Quality before system installation. Being a pressure part hydro test if mandatory .
6. Results & Experimental validation- Recording of results is essential to calculate efficiency and accuracy of the system. Recording results and Validation of result by comparing with performance parameters.

4. Mathematical Modeling

At Valmont Structures lot of energy is going waste along with flue gases. The potential of available heat duty is calculated as below

Available Heat Duty

$$Q = m.Cp.(Tin - Tout)$$

Specific heat & mass flow rate of flue of flue gas is calculated by using combustion calculations.[7]

Calculation for Surface Area

$$Q = U.A.LMTD$$

Overall heat transfer coefficient & LMTD is calculated by using Heat Transfer Principles.[8]

Above are the basic equations used to calculate Heat Duty and Heat Transfer Area. Besides this care of pressure drop, velocity of fluid inside tube and outside tube etc. is very important. Fin effectiveness is another facture need to calculate very carefully.

5. Manufacturing & Installation

After preparation of all detailed manufacturing drawings actual manufacturing started, all QA activities were completed as per QAP. NDT were conducted prior to dispatch to site. All erection and commissioning activities at site were as per SEP. Insulation and cladding was the final site manufacturing activity.

6. Evaluation of Design

Final activity conducted was Evaluation of design. This is achieved by recording and comparing readings with performance parameters. Readings were noted almost for two months, and based on that it is concluded that pay back will be within one year. For calculation of pay back, cost of Propane considered approx. INR 38 per Kg.

7. Expected Results

After recording readings and analyzing them, it is concluded that almost 100% targets are achieved. Due to safety margins sometimes results are better than what have assumed for performance parameters.

Following are the calculated parameters from flue gas analysis and combustion calculations

Actual Amount of Air Supplied :18.1Kg/Kg of fuel
Fuel Consumption per Hr : 135 Kg/Hr
Flue Gas Flow Rate: 2583.2 Kg/Hr
Specific Heat of Flue Gas : 1.108 KJ/Kg.^{o}C
Heat Duty Available with Flue Gases: 958475 KJ/Hr

Table 1. Performance Parameters and Results

Parameter	Results
Circulating water I/L Temperature in ^{o}C	71
Circulated water O/L Temperature in ^{o}C	78.5
Flux Tank Temperature in ^{o}C	65^{+}
Flue Gas Average I/L	475

Temperature in. °C	
Flue Gas Average O/L Temperature in °C	130

8. Conclusion

After evaluation it is observed that target is achieved 100% as actual readings are very close to performance parameters, even due to factor of safety better than performance parameters. It's because Average Flue Gas Inlet Temperature was higher than what we assumed during design. Safety interlocks have been provided to overcome this condition while designing control logic. The basic purpose was to maintain flux tank temperature around 65 °C Celsius and that was achieved, this validates the design but further development is required to make heat exchangers compact and more efficient. This can be achieved by using CFD analysis and other symmetrical tools. Even one can think of hybrid heat recovery as flue gases leaving the WHRU are still having potential to recover more heat. Preheating of process material up to some extent is also possible by using these hot flue gases. It should be always keep in mind that to **Save Energy** is like to **Generate Energy** .

The pay back calculated based on two months actual readings is around 13 months and this is quite attractive. Further improvement in design and design of hybrid WHRU, as explained earlier will bring pay back less than one year and system will be more compact and efficient. Based on results Saving per hour is around 958475 KJ/Hr, assuming Net CV of Propane 48000 KJ/Kg fuel saving will be around 20 Kg/Hr, If, for a sake of calculations it is assumed that, total 260 days working per year, net saving for 260 x 24 Hrs = 6240 Hrs per year. Hence fuel saving will be 6240 x 20 = 124800 Kg/ Year. Considering Propane cost INR 38 per Kg, total cost saving per year will be 124800 x 38 = INR 47, 42,400 say 47.42 Lk. This is huge saving and indicates payback will be less than one year.

Below table gives idea about change in flue gas O/L temperature w.r.t. Flue gas I/L temperature.

Table2 Flue Gas O/L w.r.t I/L Temperature

Flue Gas I/L Temp.	Flue Gas O/L Temp.
550	225
525	200
500	176
475	153
450	131
425	110
400	90

Above readings shows that Flue Gas Inlet temperature should not drop below 425 °C as to avoid condensation of moisture content in flue gas on tubes, fins or casing. This have achieved by controlling water flow rate in heat exchanger with two way control valve.

Table 3. Heat Duty Associated w.r.t. I/L Temperature

Flue Gas I/L Temp.	Q max. KJ/Hr
550	1276015
525	1197825
500	1120091
475	1042825
450	966037
425	889738
400	813938
375	738645
350	663865
325	589604
300	515866

The table 3 indicates the heat potential available with waste flue gas, even after recovering energy for flux heating an equipment can be design for pre-heating process material.

9. Nomenclatures

Q -Heat Duty Available with Flue Gas
m - Mass Flow Rate of Flue Gas
Cp - Average Specific Heat of Flue Gas
Tin - Flue Gas Inlet Temperature to WHRU
$Tout$ - Flue Gas Outlet Temperature from WHRU
Q -Heat Duty Available with Flue Gas
U - Overall Heat Transfer Coefficient
A - Heat Transfer Area
$LMTD$ - Log Mean Temperature Difference

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