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Simulation of Improved Design for Ammonia Plant Front End Waste Heat Boilers

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Abstract - *This paper is focused on the improved design of an ammonia plant front-end waste heat boilers. The study covered the initial design, the failure rate, and causes over a given period of time. The initial design is a set up of two bayonet tube exchangers and a straight fixed tube exchanger vertically inclined, which is prone to failure primarily because of the configuration, while the improved design is a single floating head exchanger horizontally inclined. The improved designs and their functionality have been analyzed as regards the ammonia plant understudy, and cost-effectiveness evaluated. The properties and conditions of the front end section at various rates were used to simulate the improved design via Aspen HYSYS. The improved design at 70%, 80%, 90% and 100% front end rate gave heat duties of 6.578e+08kJ/hr,8.095e+08kJ/hr, 8.188e+08kJ/hr and 9.787e+08kJ/hr respectively. When compared to the heat duties of the present design under similar conditions, the heat duties of the improved design were higher at the different front-end rates showing higher efficiency. Thus, the single improved exchanger with a quite low failure rate can comfortably replace the three front-end waste heat boilers and, in turn, increase throughput and drastically drop overhead running cost.*

Keywords — *ammonia plant, aspen hysys, process design, logistic regression modeling, waste heat boilers.*

I. INTRODUCTION

Waste heat recovery unit/system is key in most engineering/production processes. A waste heat recovery unit (WHRU) is an energy recovery heat exchanger that transfers heat from process outputs at high temperatures to another part of the process for some purpose, usually increased efficiency. Ammonia production, urea production, and most steel-making plants use this process as an economic method to increase the production of the plant with lower fuel demand [1].

Waste heat recovery is an intrinsic part of Ammonia production where heat generated during the production process is channeled into other uses, which include steam production, heating media to other parts of the production process, etc. Over 100 ammonia plants worldwide use reformed gas waste boilers featuring bayonet-style tube bundles for heat recovery in the front end section of ammonia production. Most ammonia plants built by Legacy Kellogg (KBR) from the 1960s to the 1980s make use of three (3) waste heat boilers in the front end section, two of which are bayonet water tube boilers and a straight fixed tube sheet boiler, numbered as 101-CA, 101-CB and 102-C respectively [2].

The two bayonet water tube boilers make use of the heat in the process gas on the shell side of the exchanger with boiler feed water on the tube side coming from an elevated steam drum, while for that of straight fixed tube sheet boiler (102-C), the process gas goes through the tube side and the boiler feed water on the shell side [3]. Analysis of some of the ammonia plants having bayonet boilers shows the significant loss in production attributed to the mechanical failure of these aging boilers. These ammonia production plants have recorded no improvement on the existing waste heat boilers (101-CA/CB). The design of the boilers operating at increased capacity increases the heat flux across the bayonet tubes, increases the rate of vaporization, and reduces the residence time in the steam drum, which has increased the rate of tube failure [2].

From the design of most bayonet tube boilers, it is expected that the equipment comes out efficient, effective, and robust, being active for several years before any tube should fail. The efficiency was delivered, but longevity became a challenge as some of this equipment experienced tube failures within the few months of plant commissioning.

An increase in downtime contributes to higher loss of production with the increasing cost of maintenance associated with ammonia plant front end waste heat boilers tube failure.

Analysis and research carried out on the subsequent failure of bayonet tube exchangers in the front end section of most ammonia plants showed that these failures are related to the design of the heat exchangers; for the legacy, Kellogg designed bayonet tube boilers, the following were criticized as regards its design [2]:

- Deposits at the bottom of the scabbards- due to the vertical configuration of the exchanger, deposition of debris at the bottom is made possible, which leads to scale formation, thereby inducing hot spots formation and higher failure rate

- Metal liner- As temperature increases during normal operation, the metal liner wraps and gets out of shape; in this case, maintenance work of pulling out tube bundle without damaging it becomes impossible.
- Flow disruption – spacers on the outside of the bayonet disrupt flow patterns, thereby creating hotspots. With use, the clearance between the scabbard and spacer increases; this will result in a more rigorous rub-off between the spacer and the scabbard. This continuous friction reduces the protective magnetite layer, thereby exposing the tubes to imminent failures.

Boilers are an important source of energy in the process industries because they supply steam to operate process equipment and produce the steam used throughout the processing facility. Examples of process equipment that uses steam include turbines, reactors, distillation columns, stripper columns, and heat exchangers [4], [5]. A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. When water is boiled into steam, its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be extremely dangerous equipment that must be treated with utmost care [6], [7]. A steam boiler is a closed vessel, generally made of steel, in which water is heated by some source of heat produced by combustion of fuel and ultimately to generate steam. Steam is the gas formed when water passes from the liquid to the gaseous state [8], [9], [10**].**

Waste heat is the energy associated with waste streams of air, exhaust gases, and/or liquids that leave the boundaries of an industrial facility and enter the environment. In the definition of waste heat, it is implicit that the waste streams eventually mix with atmospheric air or groundwater and that the energy contained within them becomes unavailable as useful energy. The absorption of waste energy by the environment is often termed thermal pollution. In a more restricted definition, waste heat is the energy that is rejected from a process at a temperature high enough to permit the recovery of some fraction of the energy for useful purposes in an economic manner [11].

Waste heat in manufacturing is generated from several industrial systems distributed throughout a plant. The largest sources of waste heat for most industries are exhaust and flue gases and heated air from heating systems such as high-temperature gases from burners in process heating; lower temperature gases from heat-treating furnaces, dryers, and heaters; and heat from heat exchangers, cooling liquids, and gases. While waste heat in the form of exhaust gases is readily recognized, waste heat can also be found within liquids and solids. Waste heat within liquids includes cooling water, heated wash water, and blow-down water. Solids can be hot products that are discharged after processing or after reactions are complete, or they can be hot by-products from processes or combustion of solid materials. Other less apparent waste heat sources include hot surfaces, steam leaks, and boiler blow-down water. Table 1 shows typical major waste heat sources along with the temperature range and characteristics of the source [12].

Table 1. Temperature Range and Characteristics for Industrial Waste Heat Sources

Waste Heat Source	Temp. Range °F	Temp. Range °C	Cleanliness
Furnace or heating system exhaust gases	600 – 2,000	316– 1,100	Varies
Gas (combustion) turbine exhaust gases	900 – 1,100	480 – 600	Clean
Jacket cooling water	190 – 200	90 – 100	Clean
Exhaust gases (for gas fuels)	900 – 1,100	480 – 600	Mostly clean
Hot surfaces	150 – 600	65 – 316	Clean
Compressor after or intercooler water	100 – 180	38 – 82	Clean
Hot products	200 – 2,500	100– 1,370	Mostly clean
Steam vents or leaks	250 – 600	120 – 316	Mostly clean
Condensate	150 – 500	65 – 260	Clean
Emission control devices – thermal oxidizers, etc.	150 – 1,500	65 – 816	Mostly clean

Waste-heat recovery, also known as Thermal-heat recovery, can be defined as the use of heat energy that is released from some industrial processes and that would otherwise dissipate into the immediate environment unused. Given the prevalence of heat-generating processes in energy systems, such as those found in household heating and cooling systems and in electricity generation, thermal-heat recovery has a wide area of potential applications and can reduce fossil-fuel consumption. However, although sources of waste heat are ubiquitous, not all waste heat is suitable for thermal-heat recovery, and economic or technical constraints sometimes preclude the use of available recovery technologies.

Umesh [2] on "KBR's improved design for Waste Heat Boilers in Ammonia Plant," pinpointed that the frequent failure of the front end Ammonia plant waste heat boilers is largely attributed to the Design Configuration; he went ahead to explain that the for the improved design for the Front end waste heat boilers, the two (2) bayonet tube boilers and a straight fixed tube sheet boiler are replaced by a single floating head exchanger. The new exchanger is designed for the higher duty required for increased capacity.

A study conducted by Zakaria and Hashim [14] on 'Corrosion-erosion on waste heat recovery boiler system via blowdown optimization' has shown that the chemical condition of the water-steam cycle can still be maintained even though the frequency of the blowdown is reduced. Boiler blowdown must be carried out if one of the chemical parameters in the water and steam cycle is trending upwards and reaching the limit value.

Naiem [15] has revealed that during design, the number of baffles, their height, and distribution at the evaporation zone should be carefully calculated to avoid the concentration of the heat load at a certain zone. Gas inlet pipe should be carefully treated in the design step to prevent heat localization.

According to Singh *et al.* [16], the main problems faced by the boilers are agglomeration, slagging, fouling, caustic embrittlement, fatigue failure, and high-temperature corrosion.

Corrosion inhibition is one of the methods that has been used to protect and increase the life of metallic cultural heritage. A large amount of scientific literature is available on corrosion inhibitors, but the majority of it deals with fundamental studies of corrosion inhibition or industrial applications. The rate of corrosion increases with the increase in temperature. An increase in pressure also implies an increase in the corrosion rate. However, the rate of corrosion also depends on the nature of the gas. With the increase in partial pressure of oxygen, the rate of corrosion increases, and moreover, carbon dioxide partial pressure is less sensitive to the rate of corrosion. On the other hand, noble gases do not change the rate of corrosion rate at all.

Martens and Porter [17] discussed that waste heat boilers failure is majorly caused by effects emanating from Excessive temperature, mass flux rate, Water-side tube fouling, and Process-side tube fouling.

According to the research work by Al-Mulhim [18], it has been stated that Boiler Water quality is a frequent contributing factor for tube failures. Severe operating conditions and special design features provide little operational flexibility and demand very strict water quality control. Boiler water irregularities can cause deposits, which get collected at the bottom of the shell in a horizontal fire tube type waste heat boiler. This leads to aggressive under-deposit corrosion, especially in high heat flux areas, i.e., at the tube inlet side. Failure in the bottom row of tubes also explains this phenomenon. To avoid under-deposit corrosion problems, periodic chemical cleaning from the waterside may be considered. Inspection including tube thickness measurement in every turnaround is highly recommended

Mazouz and El Bou [19] further elaborated on the fact that recovering waste heat losses provides an attractive opportunity for an emission-free and less costly energy resource. The mean factors that affect heat recovery are heat quantity, heat quality, and temperature.

Based on the increased rate of tube failure associated primarily with the design of the exchangers, the need to come up with an improved design for the front end waste heat boilers in ammonia plant arose, which will reduce plant downtime, drop the cost of production and increase ammonia production.

For the ammonia plant being considered, the front-end waste heat boilers are made up of Two Bayonet tube exchangers and a straight fixed tube sheet boiler. The bayonet tube exchanger has a layer of refractory on the inside covered both ends with a liner, a pressure plate to withstand pressure. It is protected by jacket water in the jacket water compartment before the external shell. The metal shell is designed for about 200ºC. The diameter of the metal liners and the exchanger baffle diameter is selected so that at operating temperature, a tight seal is formed, which prevents gas from passing the heat transfer area. The bayonet tube exchanger, as shown in Figure 1 below, has multiple tubes with the inner tube (bayonet) open at both ends, the outer tubes (scabbards) are closed at the bottom end [2].

The improved design is geared towards reducing the failure rates by correcting the design flaws of the current waste heat boilers being used, thereby dropping the overhead cost of running the plant. This study, therefore, aims to investigate and confirm that the proposed improved design will be a better replacement for the current front-end waste heat boilers, considering the cost. To achieve this, the factors responsible for frequent tube failures of the Kellogg (KBR) designed bayonet tube and straight tube sheet boilers have been investigated as they concern the ammonia plant being considered.

II. METHODOLOGY

The methothody employed in this research work involves the stepwise approach, which is divided into two (2) major aspects, Data collection, and Simulation using ASPEN HYSYS.

Data collection

To carry out thorough research work, various data sets are to be analyzed as regards varying conditions of the plant, specifically as it pertains to the front-end process waste heat boilers. This will give us a complete understanding of the performance and efficiency of the waste heat boilers. The same data sets at the varying conditions would be used on the improved design of the waste heat boilers using a process analyzing software (ASPEN HYSYS) to predict the various outcomes if it were to be installed in the stead of the present waste heat boilers.

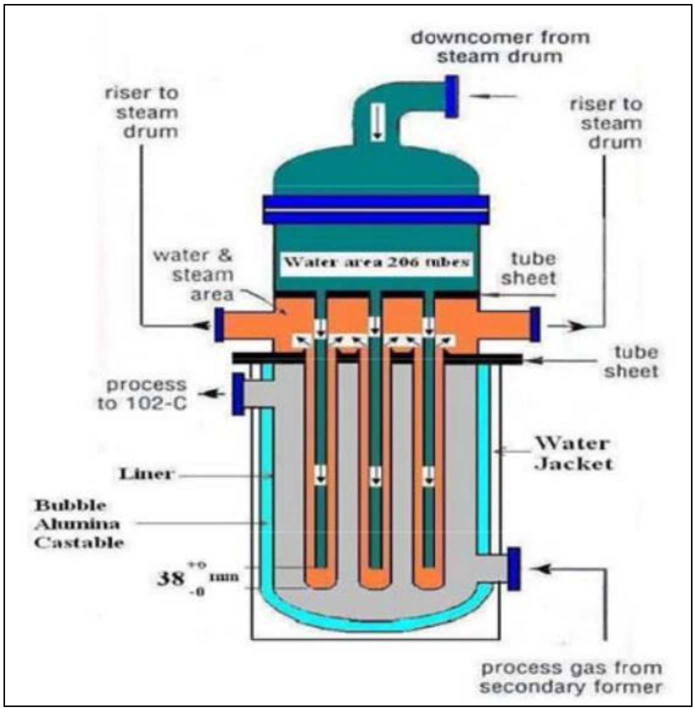

Figure 1. Bayonet tube exchanger

The simulation paints a real-life scenario of what the efficiency and performance of the improved design of the front end process waste heat boiler should be if installed.

The various categories of data sets collected from an Ammonia Plant in Rivers State, Nigeria, at different conditions are as follows:

- The design parameters of the front-end process waste heat boiler (s) system.
- Temperature, pressure, gas compositions, and mass flow rates of the respective streams during the first operational year after the plant was commissioned and running at maximum plant's front end rate.
- The running data before and after (after repair/replacement) the first recorded failure of the front end process waste heat boiler (s).
- The running data before and after (after repair/replacement) subsequent failures of the front end process waste heat boiler (s).
- The present running parameters of the front-end process waste heat boiler system.

Simulation Process

For the simulation, ASPEN HYSYS version 8.8, being a process simulation tool, was used. The software was installed on a 4 GB-64bit computer system. After installation, the software was launched to execute the simulation of the process being modeled. Upon opening the ASPEN HYSYS software installed on the computer, a user-friendly interface on this interface comes on, where one can click on NEW to carry out a new simulation project. On this new project interface, two important segments were used, namely Properties and Simulation, and it is necessary to navigate each of them in other to carry out the simulation excellently.

The property segment takes the properties of the process streams being modeled. The properties include the various components/constituents of the process gas stream and boiler feed water stream. In the properties section, the component list and the fluid packages are employed.

Component List: In this section (Fig. 2), constituents of both streams are selected from the list of components.

Navigation: on the new project interface, click on the component list and click 'Add'; this opens a new environment; on this environment, the components of the streams involved are selected by typing in the name of the component in the 'search for' box, this will bring up the component from the list of components on an alphabetical order basis, click on the component and click add to move the said component to the selected component page. Repeat this for the other components.

Fluid Packages: In this section, the property package to be used for the simulation is selected. The selection is based on the nature and composition of the process being modeled. The fluid packages are for different processes like hydrocarbon, chemical reactions alongside hydrocarbons, pure chemical reactions, thermodynamic processes, e.t.c.

For the process being modeled, we have more chemical reactions alongside few hydrocarbon components; the **CHIEN NULL** property package defines this process and has been used.

- **Navigation:** Click on fluid packages, go through the list of property packages, and select the Chien null package.

At this point, the comprising components have been added and the property package to model the process selected. The next phase will be the proper simulation process.

Simulation

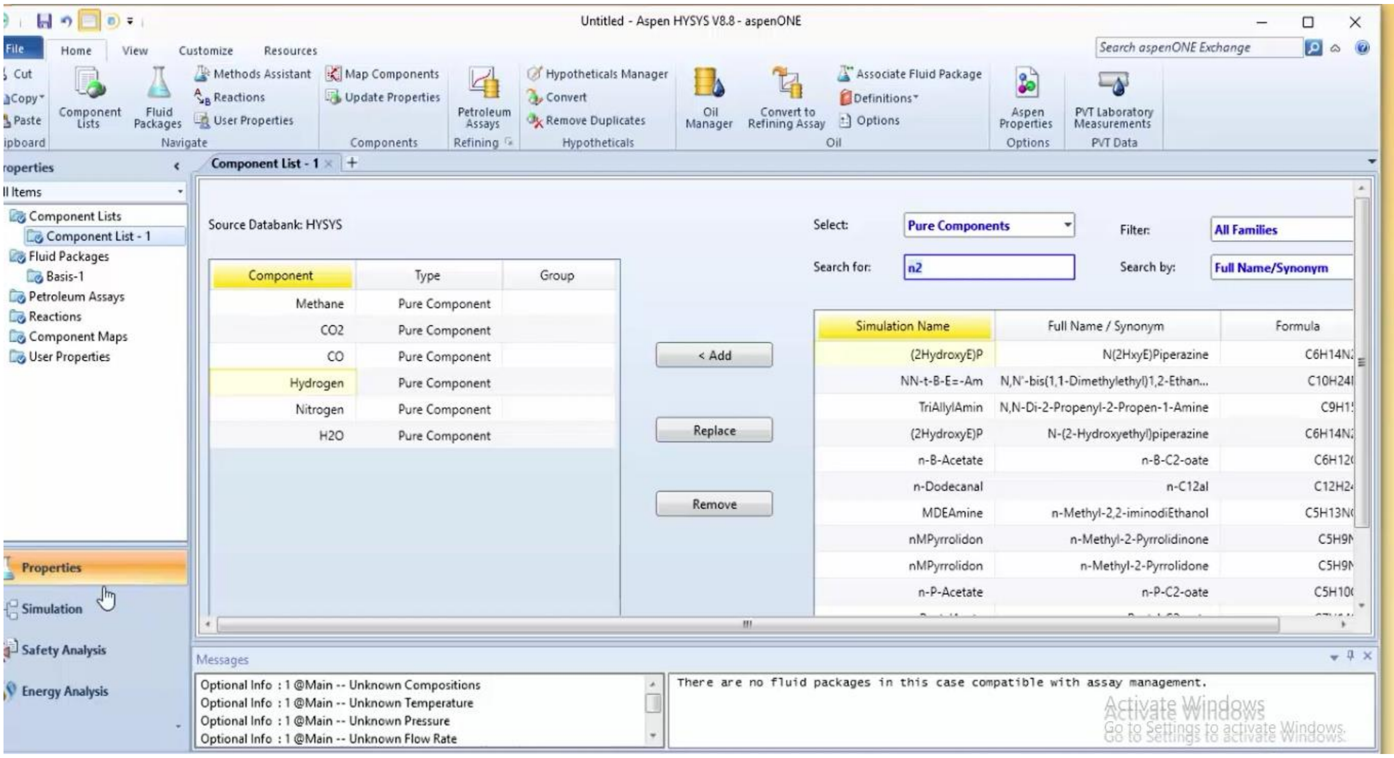

Figure 2. ASPEN HYSYS V8.8 Component Lists Interface

In this stage of the modeling process, the process is simulated to understand the behavior and outcome in a practical scenario. This entails imputing the properties of the process streams (data collected) and diagrammatically representing the process with the adequate process flow diagrams of the various items that make up the process. If the simulation process data are complete and well-articulated, the HYSYS software solves for the other properties that define the process, and this will give the complete conditions of the modeled equipment and process.

- **Navigation:** Click on SIMULATION (left bottom corner of the new project home page). This opens the 'FLOWSHEET/MODIFY PAGE' as shown in Figure 3.4 (Appendix B). On this page, click on 'models and streams'; this will call up the process palette made of a diagrammatic representation of process equipment and streams.

From the palette, pick a process arrow to the flowsheet window representing a process stream, double click on this process stream (Process gas stream) to input the various data showing the properties of the stream, a window 'material stream' comes up made of the worksheet, attachments, and dynamics. On the worksheet panel, go-to composition and input the mole fractions of the individual constituents, after which, navigate to the condition (still on the worksheet window); this opens a list of functions one can perform.

Rename stream name from Stream 1 to Process gas from S.R. (secondary reformer). Input the data collected against the respective data type; Temperature (ºC), Pressure (kg/cm2) and Mass flow (tonnes/hr). This completes the definition of the process gas stream, closes the material stream window.

Go to the process palette and pick the second stream representing the Boiler feed water stream. Click on the stream arrow and repeat the steps taken for the process gas stream. Upon completion, the boiler feed water stream has been defined.

Return to the flowsheet and pick an exchanger symbol 'E-100' from the palette to the flowsheet space. Click on the exchanger icon to open the exchanger window made up of Design, Rating, Worksheet, Performance, Dynamics, and Rigorous Shell & Tube. On the design window dropdown, go to connection (left-hand corner), select the tube side inlet 'BFW' (boiler feed water) and shell side inlet 'process gas,' label the tube side outlet 'BFW /Steam Mixture to Steam Drum' and also the shell side outlet as 'Process Gas To HTS.' Click on parameters and input the process drop on both the shell and tube sides.

Click on Worksheet on the E-100 window and input the known parameters on the process gas outlet stream (Temperature). If the parameters are accurate, HYSYS using the Chien Null property package will model/ solve the process, thereby calculating the other parameters needed to accurately design the Heat exchanger/process; this explains the Exchanger's efficiency. Once solved, the lower part of the exchanger will show 'Solved,' indicating a successful simulation process. Formatting of the process diagram can also be done on the flowsheet window, and this enables one to edit the exchanger icon configuration, adjust the flow lines and make changes to the names of the individual streams and equipment.

Process datasheet

For any process successfully modeled on ASPEN HYSYS, the corresponding datasheet defining the process is made available and can be generated. The datasheet gives an overview of the different parameters/properties of the modeled equipment/process. The datasheet enables one to make accurate deductions, comparisons, and modifications.

- **Navigation:** To generate the datasheet of the process, On the flowsheet window, right-click on the exchanger icon and select 'print datasheet,' a window pops up, click on preview, the datasheet showing the various parameters that make up the model will come up, one can save the file and print later.

Specific Heat: Is defined as the amount of heat energy needed to raise 1 gram of a substance 1°C in temperature or the amount of energy needed to raise one pound of a substance 1°F in temperature.

$$Q = mCp(T_2 - T_1) \quad \textbf{(1)}$$

Where:

Q = heat energy (Joules) (Btu);

m = mass of the substance (kilograms) (pounds);

Cp = specific heat of the substance (J/kg°C) (Btu/pound/°F);

$(T_2 - T_1)$ = is the change in temperature (°C) or (°F).

The higher the specific heat, the more energy is required to cause a change in temperature. Substances with higher specific heat **require more heat energy** to a lower temperature than do substances with low specific heat.

The main basic Heat Exchanger equation is given as:

$$Q = UA\Delta T_m Q \quad \textbf{(2)}$$

The log mean temperature difference **ΔTm** is given as:

$$\Delta T_m(°F) = \frac{(T_1 - t_2) - (T_2 - t_2)}{In(\frac{(T_1 - t_2)}{(T_2 - t_1)})} \quad \textbf{(3)}$$

Where:

T_1 = Inlet tube side fluid temperature;

t_2 = Outlet shell side fluid temperature;

T_2 = Outlet tube side fluid temperature;

t_1 = Inlet shell side fluid temperature.

Note: When used as a design equation to calculate the required heat transfer surface area, the equation can be rearranged to become:

$$A = \frac{Q}{U\Delta T_m} \quad \textbf{(4)}$$

Where: **A =** Heat transfer area (m²) (ft²);

Q = Heat transfer rate (kJ/h) (Btu\h);

U = Overall heat transfer coefficient (kJ/h.m².°C) (Btu/h°F);

ΔT_m = Log mean temperature difference (°C) (°F).

C_t = Liquid specific heat, tube side (kJ/kg°K) (Btu/lb°F);

C_s = Liquid specific heat, shell side (kJ/kg°K) (Btu/lb°F).

For a given heat transfer service with known mass flow rates and inlet and outlet temperatures, the determination of **Q** is direct, and **ΔTm** can be easily calculated if a flow arrangement is selected (e.g., **Logarithmic Mean Temperature** difference for pure countercurrent or concurrent flow). The literature has many tabulations of such typical coefficients for commercial heat transfer services.

Front end waste heat boilers; design and configuration

The straight fixed tube sheet exchanger is not equipped with a jacket water system since it handles temperatures much lower than that of the bayonet tube exchanger. The figure below (Fig. 3) depicts the configuration of the front-end heat exchanger.

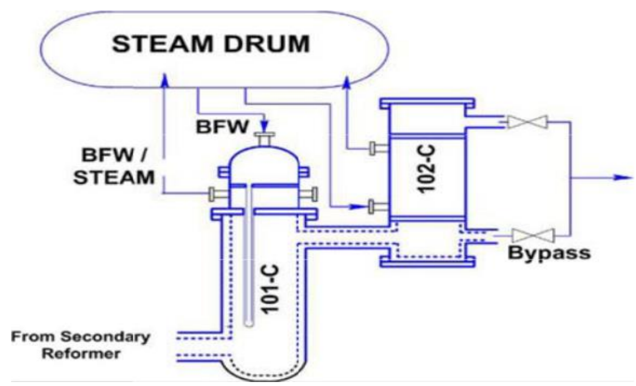

Figure 3. Ammonia plant Front end waste heat boilers set-up

The proposed improved design is a single unit water tube boiler with a floating head configuration with dual refractory lining water jacketing on the outside. The inner refractory layer is for heat conservation, and the outer layer is for erosion protection. There is no metal liner in this design. The exchanger baffle diameter and the inside diameter of the refractory are set such that they form a tight seal at operating conditions. At ambient conditions, there is enough clearance between the refractory and baffles that the tube bundle comes out easily. Figure 4 below shows the heat exchanger design windows, while Figure 5 presents the configuration of the proposed improved waste heat boiler.

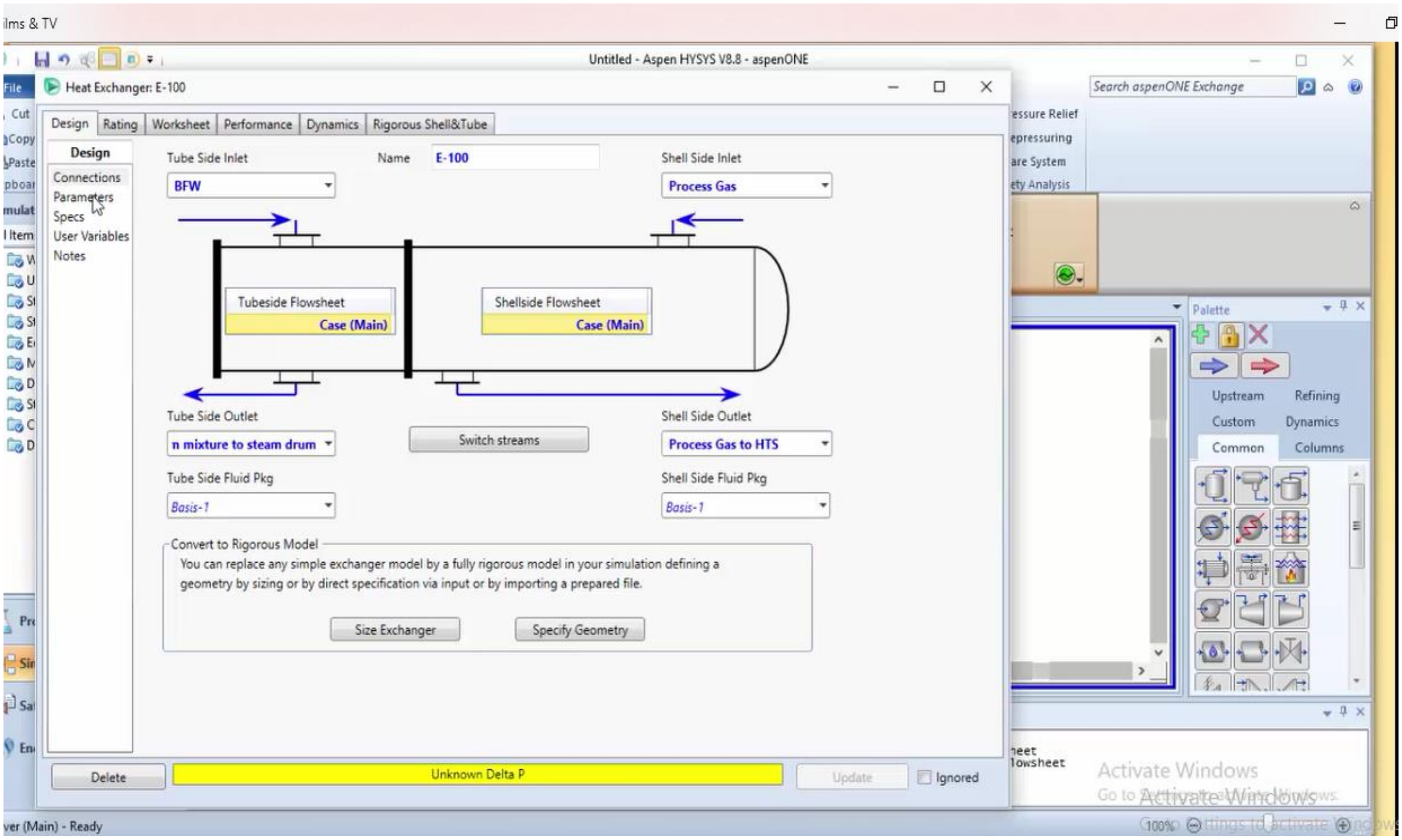

Figure 4. Heat Exchanger Design Window

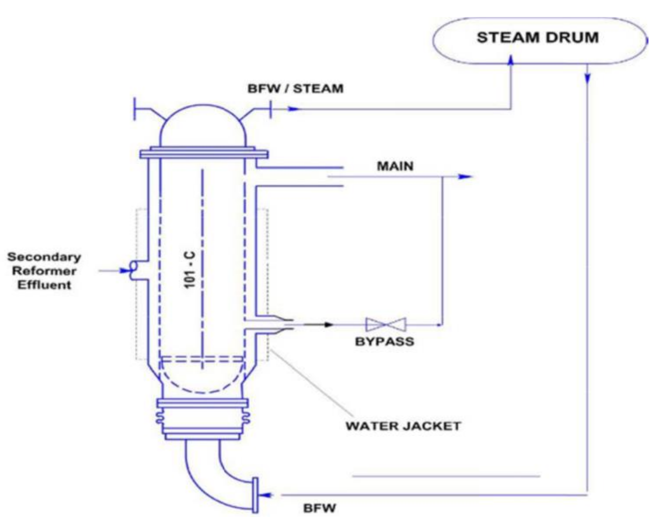

Figure 5. Improved Waste heat boiler

III. RESULTS AND DISCUSSION

The efficiency of any heat exchanger depends primarily on the amount of heat it can either absorb or give out, and this explains its performance. The primary (101-CA and 101-CB) and secondary (102-C) waste heat boilers in the front end of Ammonia production are prone to failures which are primarily based on their designs and configuration; these failures have led to an increase in the running cost of ammonia production thereby decreasing the plant's throughput.

For the purpose of this study, simulation using real-time Ammonia Plant front end data was carried out at Front end rates ranging from 70% to 100% with an interval of 10%. This returns various results, including the heat duty at the respective Front end rates. The results are compared to the existing data of the three Waste heat boilers (101-CA, 101-CB, and 102-C) currently being used. The comparison verifies and authenticates the proposal of replacing these three Waste heat boilers with a single but more efficient Waste heat boiler in other to reduce running cost and maximize profit.

Typical running data at 70% frontend rate for the 101-C simulation are shown in Table 2, and the corresponding Simulation data with the results obtained using the Process simulation tool, ASPEN HYSYS V8.4, are presented in Table 3. It is clearly evident from the data presented that the improved design waste heat boiler performs better under the same running conditions of the three front-end waste heat boilers currently in use.

Table 2. Running Data at 70% Front end rate for 101-C Simulation

Fluid Allocation	**shell side**		**tube side**		
	IN	OUT	IN	OUT	
Fluid Name	**sec. reformer effluent**		**boiler feed water**		
Temp., **°C**	984	371	306	306	
Vapour **kg/hr**	109340	109340			
Pressure **kPa**	2451.66	2157.46	9022.12	8963.28	
Components	H_2	N_2	CO	CH_4	CO_2
Mass fraction, %	62.2	19.2	8.4	0.4	9.8

Table 3. HYSYS Simulated Data at 70% Front end rate

Name	unit	Secondary reformer effluent	bfw from steam drum	process gas to hts	steam-bfw mixture to steam drum
Vapour		1	1	1	1
Temperature	°C	984	306	371	306
Pressure	kPa	2451.7	9022.1	2157.5	8963.3
Molar Flow	Kgmole/h	35082.4776	10242830.28	35082.4776	1.024 E+7
Mass Flow	kg/h	109340	184525616.7	109340	1.845 E+8
Std Ideal Liq Vol	m3/h	1025.4902	184897.997	1025.4902	184898
Molar Enthalpy	kJ/kg mole	2.50E+04	-2.37 E+05	6203	-2.36 E+05
Molar Entropy	kJ/kg mole-	180.5	102.6	161.2	102.8
Heat Flow	kJ/h	8.75E+08	-2.42 E+12	2.18 E+08	-2.42 E+12

Overall/Detailed Performance

NAME	UNIT	VALUE
Duty	kJ/h	6.58E+08
Heat Leak	kJ/h	0
Heat Loss	kJ/h	0
UA	kJ/C-h	2.51E+06
Min. Approach	°C	65
Lmtd	°C	262
Hot Pinch Temp	°C	371
Cold Pinch Temp	°C	306
Uncorrected Lmtd	°C	262

A summary of the overall heat duty for both the three waste heat boiler systems and that of a single waste heat boiler is presented in Fig. 6. Comparison of the data presented has shown that the percentage variation between the heat duties derived from the running data and that of the design data as it concerns the three waste heat boiler systems varies with the front end rate from 2.85% at 70% front end rate to 4.08% at 100% front end rate. The percentage variation is a guide as to how the heat duty for the single waste heat boiler system will look like on actual run [20], [21], [22]. This will help in a more accurate cost analysis as regards the improved design. It is clearly evident from Fig. 6 that the improved design waste heat boiler performs better under the same running conditions of the three front-end waste heat boilers currently in use.

Cost Analysis

The Ammonia plant under study is designed to produce 1000MT/day of Ammonia and CO_2 as a by-product. Both are used in the production of 1500MT/day of urea. One (1) metric tonne of urea is sold at about ($338.03). In 2015, the tube bundle of one of the primary waste heat boilers was replaced with a new tube bundle, and the secondary waste heat boiler (101-C) was completely replaced with a new one [23].

The cost analysis has been studied for a period of 4years (2015 to 2019). For these 4 years, 101-CA (installed in November 2015) has failed 7 times while 102-C (installed in November 2015) has failed thrice. For failure of any of these front-end waste heat boilers, it takes a minimum of 4days to repair and restart the plant [23], [24], [25].

Using 70% Urea plant rate and 1$ equivalent to #355 for this analysis, below is the monetary equivalent of the downtimes caused by the failure of the two waste heat boilers.

For 101-CA:

1050(daily urea production @ 70% rate)*#120,000 (price of 1MT of urea)*4 (number of days in downtime)*7 (number of times it failed in 4 years) = #3,528,000,000 ($9,938,028.2).

For 102-C:

1050(daily urea production)*#120,000 (price of 1MT of urea)*4 (number of days in downtime)*3 (number of times it failed in 4 years) =#1,512,000,000 ($4,259,154.9).

Total (101-CA and 102-C) = 3528000000+1512000000= 5,040,000,000 ($14,197,183.1).

58% of the total downtime represents average overhead cost,

Loss due to the two waste heat boilers failures= 5040000000-(0.58*5040000000) = #2,923,200,000 ($8,234,366.2).

For the Improved Waste heat boiler (101-C), the total cost of manufacturing and installing the improved waste heat boiler to replace the existing configuration of Primary and secondary waste heat boilers are summarized in Table 4 below.

Waste heat recovery is an important aspect of most chemical engineering-based process plants. It contributes to reducing the overall energy requirement in running the processes [26], [27], [28]. Modern process plant designs are targeted at reducing the energy required to the lowest possible amount; this will drop the overhead running cost. One way of achieving this energy requirement reduction is by employing adequate heat recovery mechanisms [29], [30], [31].

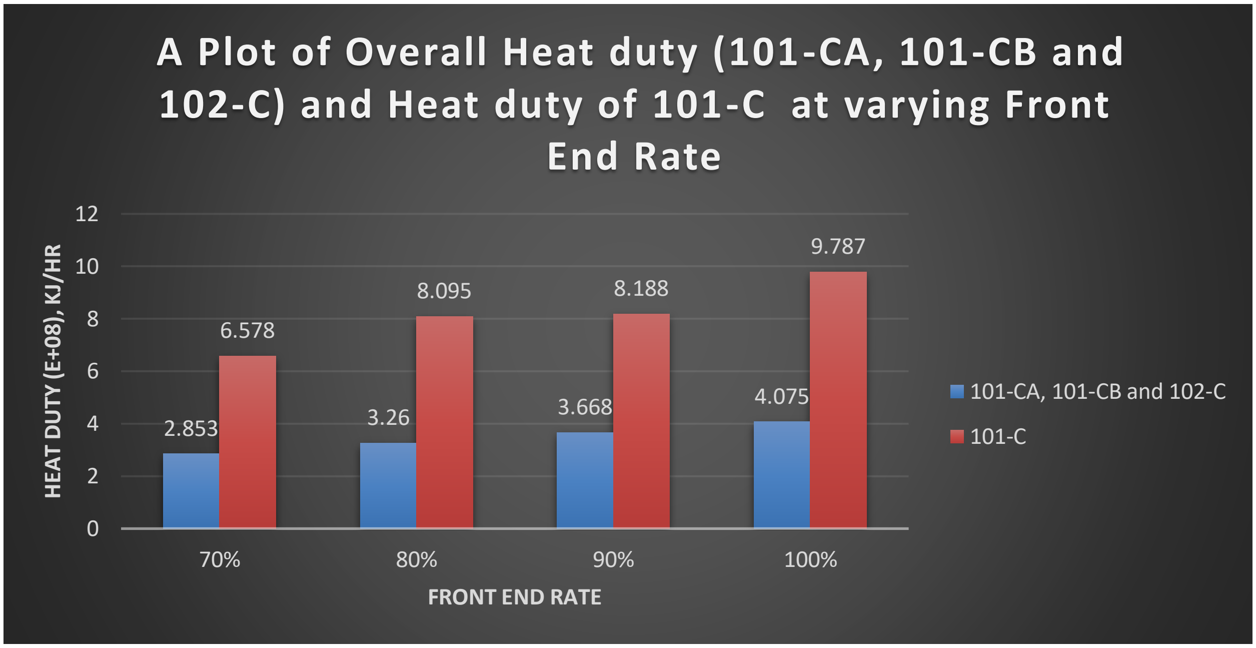

Figure 6. Graphical representation of the Heat duties at different Front End rates.

Table 4. Cost estimation for 101-C Manufacturing and installation

ITEM	PRICE
Equipment Cost (Manufacturing and Transport)	$1750000
Cost of Installation	$650309
TOTAL	$2400309
TOTAL (in naira)	852109695

IV. CONCLUSIONS

Waste heat boilers have a primary duty to recover most process heat/energy and channel it to the heat requirement of the process. The simulation results of the improved front-end waste heat boiler have shown that it can be used to replace the current configuration of Primary and secondary waste heat boilers. Its advantages over the current configuration are as follows:

- **Higher Efficiency**: The comparison between the two designs in terms of heat duties at different plant rates has shown that the improved design will perform better in the same conditions.
- **Better control to fouling**: when all three exchangers (Vertical Configuration) are replaced with the new KBR Legacy Kellogg Floating head exchanger (Horizontal configuration), it becomes easy to control fouling which is a major cause of tube failure. This can be done by cleaning the tubes from time to time via hydro-jetting. This was not possible with the bayonet tube exchangers (101-CA and 101-CB) and the straight fixed tube sheet boiler (102-C) due to their rigid designs. The cleaning gives better control to fouling and reduces the rate of tube failure.

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