International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 02, February-2017

Design and Analysis of Heat Dissipation in Clamshell Heat Exchanger

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***Abstract:* - The clamshell heat exchanger is subjected to heating and cooling cycles alternatively. The hot gases after combustion in the burner flow through the heat exchanger for 180 seconds heating the clamshell heat exchanger. This constitutes the heating cycle. The flow of hot gases from the burner is stopped after the completion of heating cycle. Now the cold air from the atmosphere is blown over the hot clamshell heat exchanger for next 180seconds the heating and cooling cycles are simulating technique in Finite element analysis using ANSYS 7.2. Firstly, the transient fluid flow analysis of gas flow region is performed to plot the velocity, pressure and temperature distributions in it. After the combustion in the burner, the gases attain a temperature of 1120˚F. These gases are blown into the heat exchanger with the help of an indoor blower for 180 seconds. The pressure gradient induced by the blower ($\Delta p = 0.0093128$ lb/in^2) and temperature of the gases from the burner (1120˚F) are applied as boundary conditions for the fluid flow analysis of gas flow region. In the cooling cycle, the air is blown over the hot clamshell heat exchanger with the help of the blower for next 180 seconds. For this purpose a two-inch airflow region is modeled over the clamshell heat exchanger. The temperature distribution in the clamshell heat exchanger after heating cycle is given as initial condition i.e., at t=0. The pressure gradient induced by the blower ($\Delta p = 0.127781e-3$ lb/in^2) Using these stress distributions the thermal fatigue life is calculated with the help of the Modified Goodman Diagram. The clamshell heat exchanger is found to be failing after 9399.37 cycles due to thermal fatigue near the first bend region.**

Keywords: Burner, Distribution, Modified Goodman, Clamshell, Furnaces

1. INTRODUCTION:

Clamshell Heat exchangers are used in residential furnaces for purpose of room heating Heat Exchangers made of finless tube bent into a compact form are also popular. Standard indoor furnaces are generally made of cold-rolled steel. If the furnace is exposed to clean air and if the heat exchanger is dry, the material has a long life and does not easily corrode. Some problems of heat exchanger corrosion and failure have been encountered because of exposure to halogen ions in the incoming air with flue gas. Combustion air contamination with laundry bleach, cleaning solvents, and halogenated hydrocarbon is common. Metallic coated material like aluminized steel or stainless steel are used for such application where corrosion resistant material is needed. The material type is aluminized steel, which is aluminum –silicon alloy (5-11% Si) coating on low carbon steel sheets by the hot dip process. The Steel sheets are available in several designations. It can produce parts containing simple bends to parts with extreme deep drawing .It has excellent heat reflectivity during exposure to temperature below 800°F(427°C), reflecting upto 80% of the radiant heat that impinges upon it. It is also an excellent heat resistant material effective to at least 1250°F. Aluminized Steel Type coating contains approximately 91% aluminum and 9% silicon that is metallurgical bonded to low carbon steel.

1.1Analysis of Clamshell Heat Exchanger:

The Thermal Stress analysis of clamshell heat exchanger is performed using ANSYS 7.2 flotran module. The analysis can be grouped under two steps as follows

1.1.2Analysis of heating cycle:

The complete combustion of Methane gas in the presence of oxygen takes place in the burner. Carbon dioxide and water vapor are the products of combustion. These products of combustion flow into the heat exchanger for a time period of 150 seconds heating the clamshell heat exchanger. The

- Calculation of velocity, pressure and temperature distribution in gas flow region
- Calculation of temperature distribution in clamshell heat exchanger using the temperature distribution in gas flow region as input.
- Calculation of thermal stress distribution in the clamshell heat exchanger using the temperature distribution in clamshell heat exchanger as input. From this stress distribution we will determine the maximum thermal stress to calculate the number of cycles under which the material is safe subjected to fatigue loading.

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1.1.3 Analysis of Cooling Cycle:

In second step Air flows over the heat exchanger for 150 seconds cooling the clamshell and eating the air.

- Calculation of velocity, pressure and temperature distribution in the airflow region and temperature distribution in clamshell heat exchanger using the temperature distribution in the clamshell heat exchanger as initial condition.
- Calculation of temperature distribution in clamshell heat exchanger after the air flow

Finally using the maximum and minimum thermal stress, we calculate the number of cycles under which the material is safe subjected to fatigue loading.

1.2 Material Properties of Aluminized steel:

Table-1: Variation of specific Heat with Temperature

Temperature (f)	Specific Heat (btu/lb-f)
1350	46.980
1200	44.892
1050	40.194
800	38.628
680	35.496
500	33.408
320	30.798
120	28.710

Table-2: Variation of Coefficient of thermal Expansion with Temperature

Temperature (F)	Coefficient of Thermal Expansion
1260	8.30E-6
1150	8.35E-6
900	8.00E-6
600	7.75E-6
500	7.50E-6
300	7.30E-6

Table-3: Variation of thermal conductivity with the temperature

Temperature (F)	Thermal Conductivity (btu/s-in-f)
1200	0.0004745
1100	0.0005324
1000	0.0005671
900	0.0006076
800	0.0006365
700	0.0006712
600	0.0006944
500	0.0007407
400	0.0007870
300	0.0007986
200	0.0008217
100	0.0008101

1.3 Pressure Drop Calculations

1.1.3 Pressure Drop calculations in Airflow

Power of the blower = Q * (Δp)

= (Discharge) * (Pressure drop)

Given Data

Power of the blower = 0.445 KW

Volume flow rate = 505 L/S = 0.505 m^3/s

Now from the above equation

(Δp) = Power / discharge

= 0.445/0.505

= 0.881 N/m^2

= 0.000127781 lb/in^2

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1.4 Pressure Drop calculations in Gas flow

Power of the Blower = Mass Flow Rate * (Pressure drop) / Density

= m * $(\Delta p) / \rho$

Given Data

Power = 0.149 KW = 0.14125 BTU/s

Mass Flow Rate (m) =8.342 lb/s

Gas Density (ρ) = 0.55 lb/m^3

Now from the above equation

(Δp) = 0.55 * 0.14125/8.342

= 0.0093128 lb/in^2

2.0 ANALYSIS OF HEATING CYCLE:

The gas flow region is modeled in ANSYS7.2 using the modeling options in Preprocessor Then it is meshed using the Hexahedral element in ANSYS i.e. FLUID141

Temperature (F)	Young's modulus	Poisson's ratio
70	0.29	0.292e8
200	0.29	0.282e8
400	0.29	0.275e8
600	0.3	0.265e8
800	0.3	0.25e8
1000	0.3	0.178e8
1200	0.31	0.128e8

Fig 9. 3D Model of the Gas flow region

The material properties of the gas are specified through the Multiple Species options in the FLOTRANSETUP.The gas is treated as composite mixture of carbon dioxide and H2 O (vapor). The values of properties of CO_2 and H_2O are given below

Table-5: Material Properties of the gaseous mixture

Property	Carbon Dioxide	Water vapor
Density (lb/in^3)	0.111605	0.03459642
Viscosity (lb/ft-s)	9.205975e-006	9.004384e-006
Specific Heat (btu/lb-f)	0.2007242	0.4810483
Thermal Conductivity	0.0083805	0.01508409

2.1.2 Boundary conditions

The following boundary conditions are specified on the Gas flow region model Velocity Boundary Condition: VX, VY, VZ is set to Zero on the areas which represent the Heat exchanger wall.

$$VX = 0;\ VY = 0;\ VZ = 0.$$

Pressure Boundary condition: Typically, in ANSYS you apply a relative pressure (usually zero) as an outlet boundary condition. In the absence of gravity and a rotating reference frame, the absolute pressure is the sum of the FLOTRAN (relative) pressure and the reference pressure. But for the flows, which are pressure driven one of the pressure boundaries, is an inlet. Here the Pressure gradient is calculated from the specifications of the Indoor Blower.

Pressure Gradient: Δp = 0.0093128 lb/in^2

Temperature Boundary condition: The inlet temperature of the hot gases coming from the burner after the combustion is given.

$$T = 1120^{\circ} F$$

Convection Boundary condition: The convection film coefficient of the hot gases is specified on the boundary. It is given as input in the form of function.

$$Nu = (0.625) * (Re)^{1/4} * (Pr)^{1/4}$$

$$\frac{(h * L)}{K} = (0.625) * (Re)^{1/4} * (Pr)^{1/4}$$

h = (0.625)*({VEL)*(({DENS}*(0.01)*1.756/{VISC})^0.25)(({VISC}* {SPHT} / {KXX}) ^0.25)

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2.1.3 Flotran setup

The following options are specified for the gas flow analysis
Solution options: Transient, Thermal, incompressible, Turbulent are turned on for the Analysis
Algorithm control: The algorithm used is SIMPLEN i.e. enhanced algorithm.
Transient control: Time Integration Method
Execution Control: The Number of global iterations and Termination criteria are specified as per requirement.

Table-6: Solvers chosen for specified degrees of freedom in gas flow analysis

DEGREE OF FREEDOM	SOLVER
VX	PBCGM
VY	PBCGM
VZ	PBCGM
TEMP	PBCGM
ENDS	PBCGM
ENKE	PBCGM
PRESSURE	PRE CONDITIONED CONJUGATE RESIDUAL METHOD
TURBULENCE MODEL	STANDARD K-∊ MODEL

3.0 THERMAL ANALYSIS OF CLAMSHELL HEAT EXCHANGER AFTER HEATING CYCLE:

3.1 Modeling & Meshing:

The temperature distribution in the clamshell heat exchanger is determined by using the result file of gas flow analysis. For this Clamshell Heat Exchanger is modeled in ANSYS7.1 using the modeling Options in Preprocessor. Then it is meshed using the hexahedral element in ANSYS THERMAL i.e. SOLID70.The material properties are specified through the material models. The clamshell heat exchanger is made of aluminized steel. The material properties of aluminized steel are tabulated in the previous section.

Fig 11. Clamshell heat exchanger Model

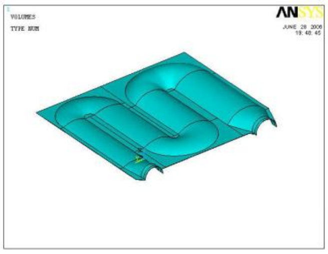

Fig 12 Meshed clamshell heat exchanger

3.2 Structural Analysis of clamshell Heat Exchanger after heating cycle:

3.1 .2 Modeling & Meshing:

The thermal stress distribution in the clamshell heat exchanger after heating cycle is determined by using the result file of thermal analysis of clamshell heat exchanger. For this Clamshell Heat Exchanger model is brought from ANSYS-THERMAL to ANSYS-STRUCT using the 'Switch to' option in preprocessor. The Clamshell Heat Exchanger mesh is converted from Hexahedral element in ANSYS-THERMAL i.e. SOLID70 to a compatible element in ANSYS-STRUCT i.e. SOLID45

The material properties are specified through the material models. The clamshell heat exchanger is made of aluminized steel. The material properties of aluminized steel are tabulated in the previous section.

4.0 ANALYSIS OF COOLING CYCLE

4.1 Modeling & Meshing

The airflow region along with the solid clamshell heat exchanger is modeled in ANSYS7.2using the modeling options in Preprocessor. A two-inch height airflow region is modeled on the solid clamshell heat exchanger with a thickness of 0.035inches.

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Fig 13 3D Model of the clamshell heat Exchanger with a 2-inch high airflow Over it

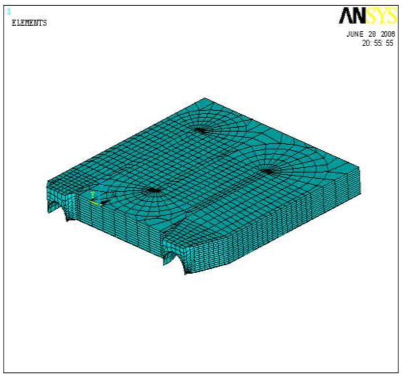


Fig 14 Meshed figure of the clamshell heat exchanger with a 2 inch high airflow over it

The gas flow region is meshed using the Hexahedral element in ANSYS i.e. FLUID 142and the solid region is also meshed with the same hexahedral element i.e. FLUID 142 .The FLUID 142 element solves only the energy equation in the solid region.

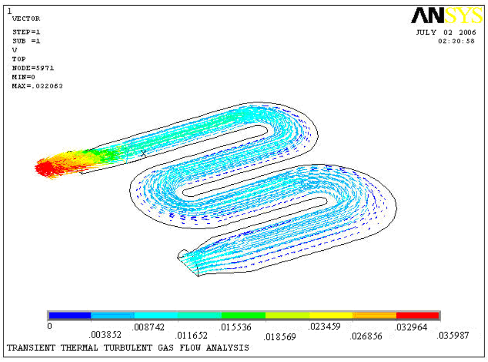
4.1.1 Initial conditions: The Temperature distribution in the clamshell heat exchanger is given as initial condition. For this a steady-state thermal analysis is to establish the initial conditions. To do so, the following steps have to be performed:

- Specify the appropriate steady-state loads (such as imposed temperatures, convection surfaces, etc.).
- Turn off transient effects.
- Extremely small time value is given for e.g. 1E-6 seconds.
- Specify ramped or stepped loading. If ramped loading is defined, the effect of the resulting temperature gradients with respect to time should be considered.
- Write the load data to a load step file. For the second load step, remember to delete any imposed temperatures unless you know that those nodes will maintain the same temperatures throughout the transient analysis. Also, remember to turn on transient effects.

4.1.2 Pressure condition: Typically, in ANSYS a relative pressure (usually zero) is applied as an outlet boundary condition. In the absence of gravity and a rotating reference frame, the absolute pressure is the sum of the FLOTRAN (relative) pressure and the reference pressure. But for the flows, which are pressure driven one of the pressure boundaries, is an inlet. Here the Pressure gradient is calculated from the specifications of the Air Blower.

$$\Delta P = 0.127781 \text{ E-3 lb/in}^2$$

4.1.3 Velocity Distributions



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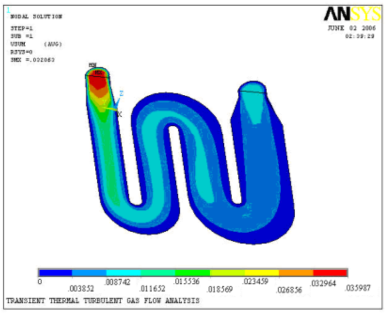
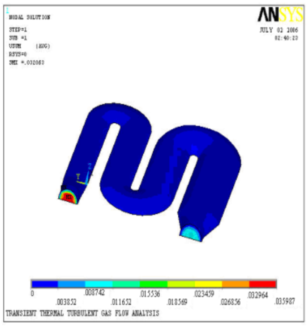
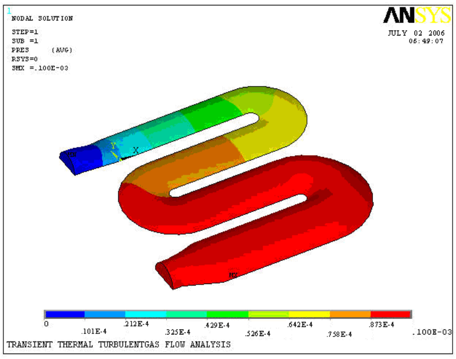
4.1.4 Vector plot of velocity distribution after the heating cycle



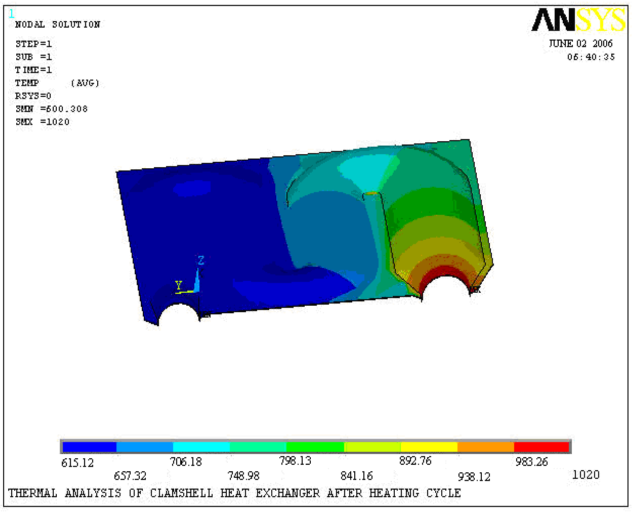


4.1.5 Velocity distribution in the gas flow region after the heating cycle

Velocity distribution in the gas flow region .The velocity distribution is based on the pressure difference given at the inlet and the outlet. Inlet velocity is not defined separately, but it is calculated depending upon the pressure difference specified. The maximum velocity is found at the exit, where the area of the cross section is minimum. The velocity is gradually increasing from the wall to the center of the conduit. The boundary layer formation is observed



4.1.6 Design And Analysis Of Heat Dissipation In Clamshell Heat Exchange:



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5.0 FATIGUE LIFE CALCULATION USING MODIFIED GOODMAN DIAGRAM

The Fatigue life of the component using the modified Goodman diagram is determined by considering the maximum and minimum stress at a particular location of the component. The location experiencing the maximum stress is chosen for the fatigue life calculation. The maximum and minimum stress experienced at that location is taken as σ_{max} and σ_{min} for the calculation of fatigue life using the modified Goodman diagram

Maximum Stress (σ_{max}) = 13 416 lb/in^2 (taken from the thermal stress distribution plotted After heating cycle)

= 92 Mpa

Minimum Stress (σ_{min}) = 830.529 lb/in^2 (taken from the thermal stress distribution coolimg)

=5.67 M Pa

Mean Stress

σ_{Mean} = 1/2 [(σ_{max}) + (σ_{min})] = 48.835 M Pa

Stress Amplitude

σ_a = 1/2 [(σ_{max}) - (σ_{min})] = 43.165 M Pa

S_{UT} = Ultimate Tensile strength = 142.72 M Pa

S_E' = 0.5 S_{UT} = 71.36 M Pa

$S_E = K_a\, Kb\, K_c\, K_d\, S_E'$

GIVEN DATA

K_a = 0.857

K_b = 0.75

K_c = 0.753

K_d =0.4533

S_E = 15.608 Mpa

Now we use Modified Goodman Diagram and calculate S_f

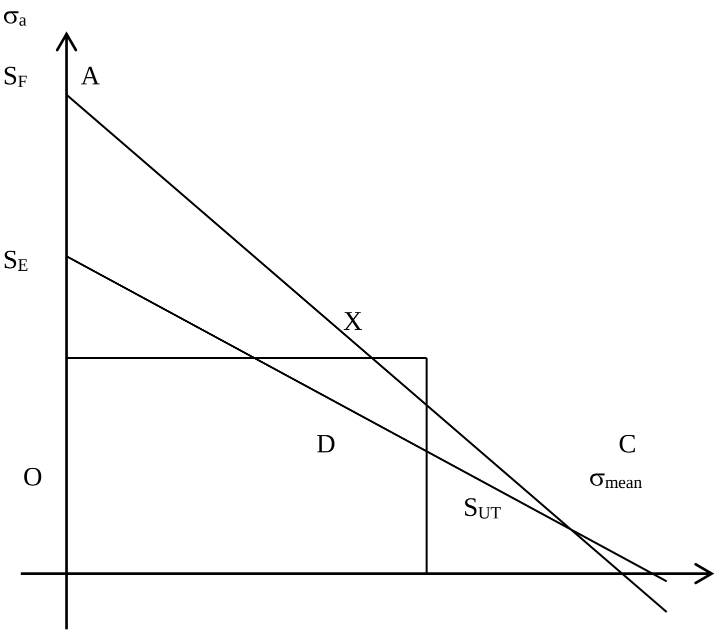

Fig 29. Modified Goodman Diagram

From Above Similar Triangles

S_F = AO = XD*OC/DC

= (43.165 * 142.72) / (142.72 – 48.835)

= 65.617 lb/in^2

$\log_{10}$ (0.9 S_{UT}) = $\log_{10}$ (0.9 * 142.72) = 2.108

$\log_{10}(S_E)$ = $\log_{10}$(15.608) = 1.193

$\log_{10}(S_F)$ = $\log_{10}$(65.617) = 1.817

From Figure

EF =DB*AE/ED

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ISSN: 2278-0181
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$= (6-3)(2.108 - 1.817) / (2.108-1.193)$
$= 0.9573$
$\log_{10}(N) = 3 + EF = 3 + 0.9573 = 3.9573$
$N = 9063.58$ cycles

6.0 CONCLUSIONS:

The failure analysis of clamshell heat exchanger has been simulated using the principles of finite element methods and the analysis software ANSYS 10.0.The velocity, pressure and temperature distributions of both the gas flow and airflow are plotted. The temperature and the thermal stress distribution in the clamshell heat exchanger after heating and cooling cycles are plotted. The thermal fatigue life is calculated from the stress distributions obtained after the heating and cooling cycles using the Modified Goodman Diagram The thermal stresses induced after the heating cycles are very high when compared to the thermal stresses induced after the cooling cycle. Hence the large stress variations are occurring in the small time span of 180 seconds. Due to these stress variations, thermal fatigue is induced in the clamshell heat exchanger. Finally the clamshell heat exchanger is failing after 9399.37 cycles due to thermal fatigue near the first bend region.

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