Study of Heating Process in Condenser of Thermokinetic Desorpter

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Abstract: ***Volatile is a substance which can change state from a solid or liquid to vapor. Gas chromatography (GC) is the instrument used to study volatiles and it can analyse molecules whose boiling points are as high as 250ºC or more. Thermokinetic Desorpter is a sampling device for GC which doesn't allow non volatile material in GC column. Condenser plays a vital role in separating volatiles from nonvolatile material. The aim of current study to analyses heating process in condenser to get optimum temperature while separating volatiles.***

Keywords: Desorptor Cartridge Heaters, Temperature, Ambient Temperature, Conductive Heat Transfer, Specific Heat.

1. Introduction

The report describes study of new approach of heating process in MATLAB environment.PDE APP MATLAB tool is used to analyses heating process. The Prototype device for this is already manufactured, which is a POC (Proof of Concept). The goal of this report is to reduce the time of heating. For the purpose of heating the envelope electrical heaters are used with sensor for establishment of feedback control system peltier chips are used for cooling process.

A method of analysis and the associated MATLAB software results are presented for the purpose of solving steady and transient state nonlinear heat transfer problem in condenser. Nonlinearity arises due to dependence of thermal conductivities on temperature as well as from presence of radioactive heat transfer.

2. Literature Review

Following literature describes the prototype thermokinetic desorpter developed previously. This device works on thermo-Kinetic Principle of extraction. The equipment contains following parts [4]:

1. PID Controller.
2. Electrical Circuit.
3. Flow and Temperature control.
4. Desorpter and Condenser.
5. Absorbent.
6. Heating and cooling Media.
7. Critical components of the system are design and geometry of Desorpter and Condenser, selection of heating and cooling media, absorbent material, and feedback control system for governing temperature, flow and Pressure.

2.1 Description of various sub-systems:

2.1.1 The Desorpter

Desorpter is a single piece unit carved out of 316 grade stainless steel (food and surgical grade, ideal for pressure reactors and boilers and is corrosion resistant) and fitted with screw cap for sample load. A GC septum or O rings secured airtight sealing. Holes are drilled in the body to accommodate the cartridge type heaters and temperature sensors. The sample compartment is cylindrical with 1 cm diameter and 5 cm length. Special care is taken to polish the interiors to avoid sample retention and subsequent contamination. Ferrule nuts are welded in the body for nitrogen inlet and effluent outlet. The heaters and sensors are connected to the thermostat and can be programmed from ambient temperature to 350^{O}C in multi steps.

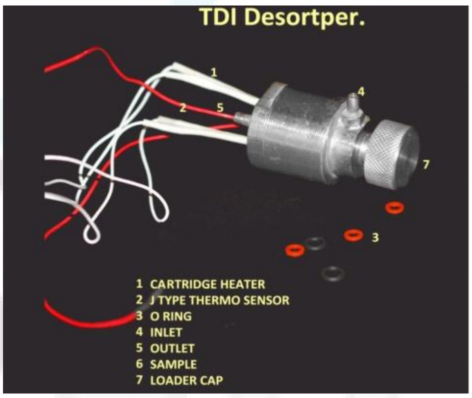

Figure 1: Old model of Desorpter

2.1.2Condenser

The condenser unit is slightly more complex than the desorpter both in functioning and in construction. The main body is 316 stainless steel cylinders with a 1cm x 6cm hole drilled in. The adsorbent material is packed in here. It has inlet and outlet holes fitted with ferrule nuts. Glass wool protects these holes from adsorbent choking. A special heater with inbuilt thermo sensors is wound around the condenser tightly. This heater is capable of heating the condenser to $250^{O}C \pm 1^{O}C$ in just 5 seconds, and maintains the temperature so. The temperature range and holding time can be programmed. An Aluminium sleeve perfectly fits around the heating element, giving it a close contact with cooling system outside. The cooling system consists of two aluminium boxes with cylindrical slit at its centre. These boxes are driven with a lever system to separate them from the condenser or to bring them close to the aluminium sleeve. The coolant used is a mixture of dry ice and acetone.

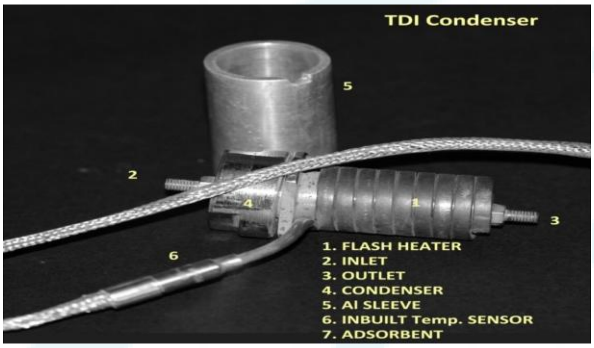

Figure 2: Old model of Condenser

2.2. Working

A solid or semisolid sample containing volatiles is heated using multiple sources in a current of dry or moist (Controlled) Nitrogen and the effluents are driven to a frigid cartridge pre-loaded with appropriate adsorbent. Once the desorption is complete, the cartridge can be flash heated and the pneumatics drive the volatiles through appropriate membrane filters to the GC for analysis. Membrane filters are used to selectively detain water molecules and molecules of particular choice.

3. Method

The function of condenser is to concentrate the volatiles by first cooling them up to -30OC and trapping it with in absorber. Absorber is a porous material which only allows nitrogen gas to pass through and will trap volatile. Again to release the volatiles absorber is flash heated up to 250OC. Then it delivers the volatile in GC machine. Fig 2 shows the view of previous condenser and porous absorbent material. We modified the design of component.

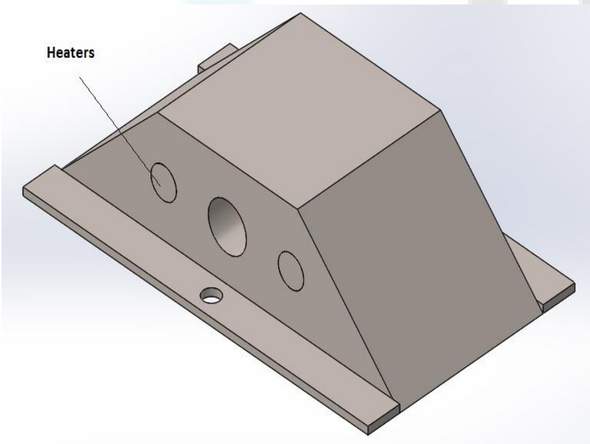

Figure 3: New modified condenser model

Figure above shows the condenser model with two cartridge heaters. Following boundary condition was applied:

Initial Temperature – $20^{O}C$

Maximum Temperature – $250^{O}c$

Heat Transferred from heaters to Condenser:

$Q = m\, c_{p\,(t_2 - t_1)}$ = 80.5 KW

Where,

m = Mass of Condenser Body
c_p = Specific heat of stainless steel

Time of heating = 300 seconds

3.1 Heating Process

After cooling process, the volatiles are trapped in the absorber porous material. Further these volatiles need to be released from the porous zone. In order to release them, we need to heat the condenser up to temperature 250Oc in 5 minutes. For heating purpose it is decided to use cartridge heaters for ease of manufacturing & operation. Special bore for accommodation were provided as shown **Figure 3**.

Wattage calculation for Cartridge heaters:

$W = \frac{Wt.Cp.\Delta T}{3412.H}$ =471.86 watts =500 watts

W = 500Watt
Wt = weight of material to be heated = 0.7 kg
Cp = Specific Heat of Stainless steel = 500 j/kg°k
ΔT = Temperature rise = 230°c
H= Heating time in Hours = 0.05
By calculation, It is decided to use 2 heaters of 250 watts.
Specification of Heaters:
Size – ø8 X 31mm
Sensor – PT 100

4. Mathematical Modeling

The partial differential equation of heat transfer in linear case is:

$$\varrho Cp \frac{\partial T}{\partial t} - \nabla.(k\nabla\, T) = Q \;(1)$$

T is the temperature, ϱ is the material density, Cp is the specific heat, and k is the thermal conductivity. Q is the heat generated. But in nonlinear condition both radiation and convection heat loss considered
Heat transfer is:

$$\varrho Cp \frac{\partial T}{\partial t} - .(\nabla k \nabla\, T) + 3hcT + 3\varepsilon\sigma T^4 = 3hcTa + 3\varepsilon\sigma Ta^4 \;(2)$$

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Where, the factors of three account for the heat transfer from three condenser faces. And Ta is a ambient temperature 300k,

The amount of heat transferred from each face per unit area due to convection is defined as:

$$Qc = hc(T - Ta) \quad (3)$$

The amount of heat transferred from each face per unit area due to radiation is defined as:

$$Qr = \varepsilon\sigma(T^4 - Ta^4) \quad (4)$$

5. Result

Partial Differential Equation Toolbox provides functions for solving partial differential equations (PDEs) in 2-D, 3-D, and time using finite element analysis. It specifies mesh 2-D and 3-D geometries and formulates boundary conditions and equations.

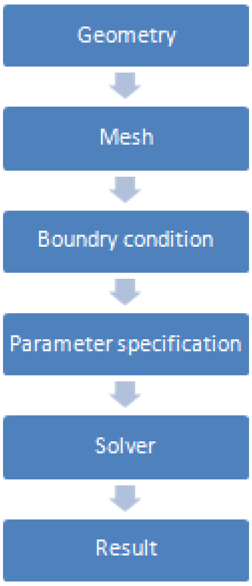

Figure 4: Process Diagram Of PDE App

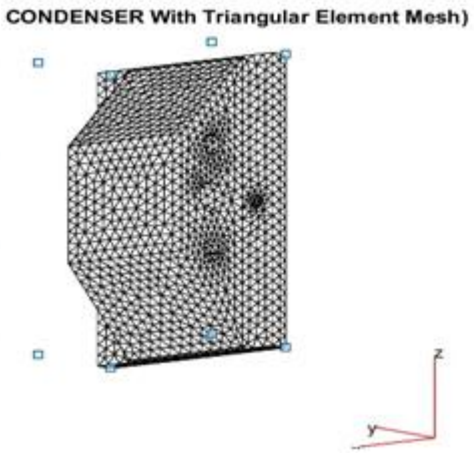

Figure 5: condenser with triangular element mesh

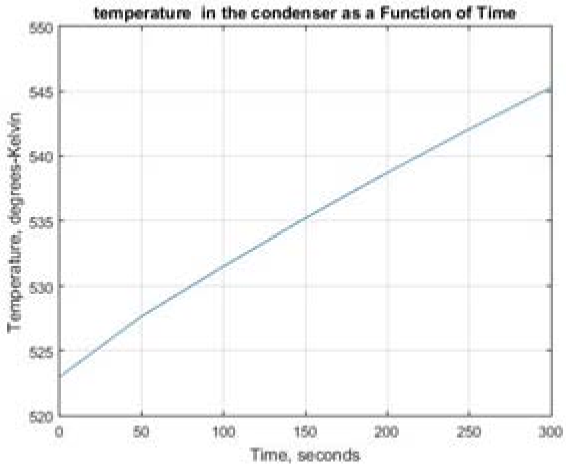

Figure 6: Graph of Temperature Vs. Time for Condenser

Figure: 6 show the relation between time and temperature rise. So the graph shows that after 100 seconds the temperature of condenser reaches near 523k.and after 300sec it reaches to548k.

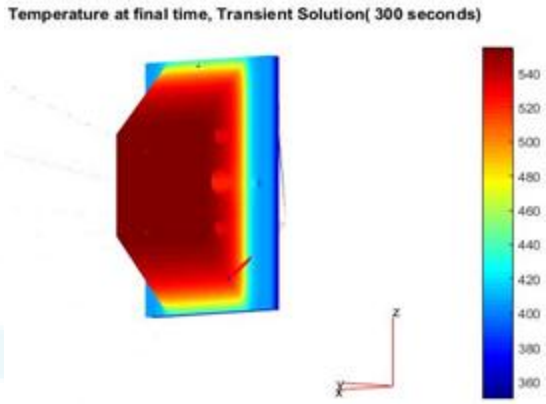

Figure: 7 Temperature contour for condenser

Figure: 7 shows temperature contour for condenser. The temperature 523k is given to the heaters and analysis shows that the complete unit will heat up near 548k in 5 minutes. The radiation, conduction, convection losses are considered.

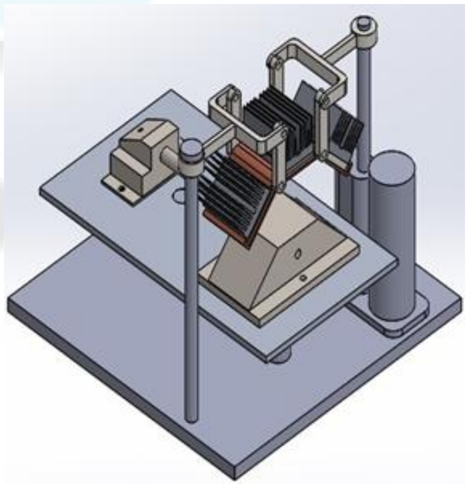

Figure 8: CAD Model of Thermokinetic desorpter Assembly with Condenser

6. Conclusion

After analyzing heating process in MATLAB environment, it is observed that overall condenser effectively heated within minimum temperature.

In the future scope, the volatile separating mechanism can be further developed by improving some factors like heating sources and more efficient peltier chips. Heating sources like Induction, magnetic, microwave and laser heating may have different results, depending on nature sample to be used in order desorbs out more molecules.

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