# Influence of Convection Heat Transfer Coefficient on Heat Transfers and Wall Temperatures of Gas-turbine Combustors

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## Abstract

*The effect of convection heat transfer coefficient on the combustor liner surface temperatures and the amount of heat that is transferred through the combined effect of radiation, convection and conduction at the surface is investigated. A computer program using pertinent parameters as input was used to handle the heat transfer computations. The results were impressive, showing how the internal and external surface temperatures are affected by varying the coefficient of convective heat transfer. The higher the coefficient, the higher the quantity of heat transferred. Higher wall temperatures are achieved with higher coefficients. But temperature difference between liner outer and inner wall surface temperatures gets larger with increased coefficients. The quantity of heat that could be expected by variation of the convection heat transfer coefficient is in the range of 70,000-85,000KJ.*

**Keywords**: *Combustor, heat transfer, wall temperature, gas-turbine.*

**Nomenclature**

| | |
|---|---|
| $A_1$ | convective and radiative heat transfer external surface area |
| $A_N$ | convective and radiative heat transfer internal surface area |
| $h_a$ | convective heat transfer coefficient for external wall surface |
| $h_i$ | convective heat transfer coefficient for internal wall surface |
| k | conductive heat transfer coefficient in the material |
| q | Transferred heat from the inner bulk fluid stream through the material wall to annular space |
| $r_i$ | radius to inner wall surface from center of cylinder |
| $r_a$ | radius to outer wall surface |
| Rac | sum of outer radiative and convective resistances |
| Ric | sum of insde radiative and convective resistances |
| Rada | radiative heat resistances for outside wall |
| Radi | radiative heat resistances for inner wall |
| Rcona | convective thermal resistances for outer wall |
| Rconi | convective thermal resistances for inside wall |
| $R_{th}$ | conductive thermal resistances in material |
| $R_{total}$ | total thermal resistance of the system: |

| | |
|---|---|
| $T_a$ | constant outer surrounding temperature, Ta = Tsurr |
| $T_i$ | internal bulk stream temperature |
| $T_{wa}$ | outer wall surface temperature |
| $T_{wi}$ | internal wall surface temperature |
| $T_{surr}$ | the surrounding temperature, - main annular temperature |
| Greek letters: | |
| ε | emissivity |
| σ | Stefan-Boltzmann constant |
| Suffixes | |
| th | thermal |
| z | distance in axial direction |

## *1. Introduction*

In gas-turbine combustors, the internal walls of the liner are always subjected to intense radiation heat. Thermally induced axial stresses or shocks occur in materials when they are heated or cooled. It affects the operations of gas turbines due to the large components subjected to stresses [1]. The combustor liners are made of small wall thickness in order to avoid much thermal stress build-up. Such controls are done at the design stage where internal diameter is pre-determined to cope with the flow rate of the hot combustion gases. Also the annular space surrounding the combustion liner pre-designed for the expected flow pattern. The internal wall temperatures of the cylindrical surface, in most cases, are made to be very close to the temperature of the radiation source. Such high wall temperatures are always damaging to the combustor liner, resulting in cracking and premature failures of the components. One of the effective ways of controlling the high wall temperatures is application of the influence of the convective heat transfer coefficient. Such influence is to act to cushion out the effect of the radiation heating.

Namgeon et al [2] carried out numerical analyses in order to understand complex thermal characteristics of a gas-turbine combustion liner such as: combustion gas temperatures, wall adjacent temperatures and heat transfer distributions. The results showed that wall adjacent temperatures and wall heat transfer coefficients in the combustion field were distributed differently throughout the combustion liner by the swirling flows. Tinga et al [3] performed gas-turbine combustor liner life assessment using a combined fluid/ structural approach.

Their observation was that different mass flow yielded different convection heat transfer coefficients. They used for inner and outer liners, convectional heat transfer coefficients ranging from 140 to 1400 $W/m^2K$, depending on the engine operating condition. The present work used varying convection heat transfer coefficients on the inner walls of the combustion liner, while maintaining a constant coefficient on the external walls. The reason for these conditions was to observe distinctly the effects of the inner heat transfer coefficients on the quantity of heat transferred and the wall temperatures as a result of exposure to intense radiation. The work used observation range of 100 to 2000$W/m^2K$.

## *2. Materials and methods*

Considering a designed combustion liner (cross-section) dimensions that is so thermally loaded as in Fig. 1,
at steady state, it can be noted that a quantity of heat, q .is transferred to outer annular space, in the direction shown in Fig, 1 (b).
As can be further noted from fig. 2 the bulk stream temperature enveloping the liner, temperature of surrounding, $T_{surr}$ = 620K.
The radiative heat resistances for inside and outside bulk streams are noted as Radi and Rada respectively. The convective heat resistances for inside and outside bulk streams are denoted by
Rconi and Rcona respectively.

$\longrightarrow$ direction of flow

The conductive heat resistance in the combustor wall material is denoted by Rth.
Then to sum up:

Ric = Radi + Rconi (1)

And, Rac = Rada + Rcona (2)

And so giving a total thermal resistance of the system:

Rtotal = Rac + Rth + Ric. (3)

Where,

Ric = sum of insde radiative and convective resistances

and, Rac = sum of outer radiative and convective resistances

The algorithm for the program to compute the steady –state end temperatures is given in fig 5. The program consists of two main modules, one for computing $T_{wa}$ and the other for $T_{wi}$ and the heat transferred in the system

**Finding the Steady-State End Temperatures - further to stipulating the tolerance condition for main program**:

Referring to Fig.1 (a), (b):

At Steady-State, the Boundary conditions are [4]:

$T = T_{wi}$ at r = ri = 35cm , inner wall radius

$T = T_{wa}$ at r= ra outer wall radius

T = Ti main stream flow temperature in combustor

Where, $T_{wa}$, and $T_{wi}$ are temperatures at the wall surfaces,

$T = T_{surr}$ at r = ra ( Bulk stream annular temperature)

For the whole heat transfer from Ti to $T_{surr}$,

$$q = \frac{(Ti - Tsurr)}{(Rada + Rcona + R_{th} + Radi + Rconi)} \qquad (4)$$

Where the sum of the radiative and convective outside thermal resistances outside

Rac = Rada +Rcona (5)

And,

Rada = the radiative thermal resistance

Rcona = the convective thermal resistance .

The sum of the radiative and convective thermal resistances inside

Ric = Radi + Rconi (6)

Also, the total sum of radiative, convective and conductive thermal resistances of the whole heat transfer system, in consideration,

$R_{total}$ = Rada +Rcona + Rth + Radi +Rconi (7)

Now, individually,

Conductive thermal resistance, Rth:

Rth = ln(ra/ri) / 2* Pi* k* z (8)

Radiative thermal resistance, outer wall surface,Rada [5]:

$Rada = 1/[бεA_1 (T_{wa}^2 + T_{surr}^2)*(T_{wa} + T_{surr})]$ (9)

Convective thermal resistance, outer wall surface

$Rcona = 1/h_aA_1$ (10)

Radiative thermal resistance, inner wall surface

$Radi = 1 /[бεA_N (Ti^2 + T_{wi}^2)*(Ti + T_{wi})]$ (11)

Convective thermal resistance, inner wall surface, Rci:

$Rconi = 1/h_iA_N$ (12)

And for the sections, heat transfer, q:

$q = (T_{wa} – T_{surr})/ Rac$ (13)

$q = (Ti – T_{wi})/ Ric$ (14)

$q = (T_{wi} – T_{wa})/Rth$ (15)

Since the heat transferred is equal,

Equations (4), (13), (14), and (15) above can be used to solve for $T_{wa}$ and $T_{wi}$:

Important Ratios involved in determining $T_{wa}$ and $T_{wi}$ are:

$(T_{wa}-T_{surr})/Rac = (T_{wi}-T_{wa})/Rth = (Ti-T_{wi})/Ric = (Ti-T_{surr})/R_{total}$ (16)

From Equation (16),

$$T_{wa} = T_{surr} + (Ti - T_{surr})*Rac / R_{total} \quad (17)$$

And,

$$Twi = Ti - (Ti - Tsurr)*Ric / R_{total} \quad (18)$$

Then,
It follows that,

$$T_{wa} = T_{surr} + \frac{(T_i - T_{surr})*(Rada + Rcona)}{Rada + Rcona + R_{th} + Radi + Rconi} \quad (19)$$

Program EU406-END TEMP in appendix 2 uses the equation (19) to calculate $T_{wa}$.
The above Equations are used in the Program EU406-END TEMP (Appendix )

## *3. Results and discussion*

For a cylindrical cross-section of a combustor of gas turbine, such as shown in Fig. 2, having internal radius as 35 cm, with a wall thickness of 0.25 cm:

The following are further noted:

| | |
|---|---|
| The compressor discharged air temperature | 620 K |
| The adiabatic temperature within the combustor liner | 2,620 K |
| A convection heat transfer coefficient, $h_a$ (external wall influence) | 20 $W/m^2K$ |
| A convection heat transfer coefficient on internal walls, $h_i$ (varying) | 100 $W/m^2K$ |
| A heat conduction coefficient in the material of the liner wall, k | 22 W/mK |
| And a wall thickness of | 0.25 cm |

With a Visual Basic Program ,radiative heat transfer and the wall surface temperatures, at steady-state, can be computed , as shown in Tables 1 & 2.

A constant coefficient, $h_a$ is maintained on the external walls, whereas different values of $h_i$ are applied on the internal walls, for other variants.

A flowchart for the computation of the required radiative transferred heat allowing for the changes in the convective heat transfer coefficient is presented as Appendix 1. The computer program for the computation of radiation heat transfer is presented as in Appendix 2.

## *5. Conclusion*

Convective heat transfer coefficients can influence the quantity of radiative heat transfer in the combustor liner of gas turbines. The higher the coefficient, the higher the quantity of heat transferred. Higher wall temperatures are achieved with higher coefficients. But temperature difference between liner outer and inner wall surface temperatures gets larger with increased coefficients.

## *6. References*

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**Appendix 1: figures**

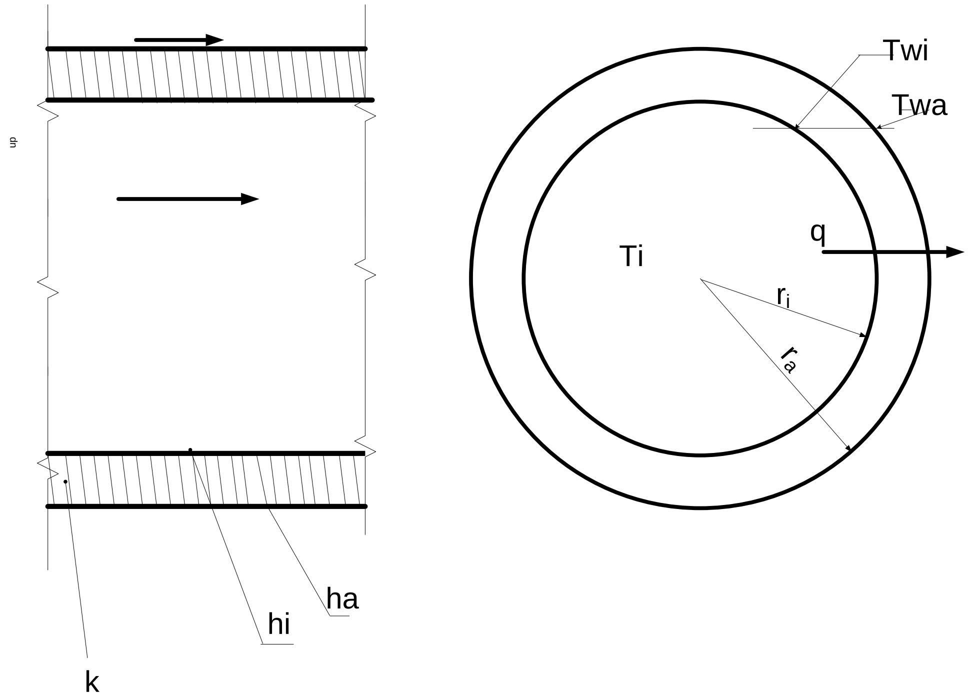


Fig. 1 (a) (b)

Cross section of Combustion liner

Legend:

- ri radius to inner wall surface from center of cylinder
- ra radius to outer wall surface
- Ta constant outer surrounding temperature, Ta = Tsurr
- Ti internal bulk stream temperature
- $T_{wa}$ outer wall surface temperature
- $T_{wi}$ internal wall surface temperature
- $T_{surr}$ the surrounding temperature, - main annular temperature
- ha convective heat transfer coefficient for external wall surface
- hi convective heat transfer coefficient for internal wall surface
- k conductive heat transfer coefficient in the material
- q Transferred heat from the inner bulk fluid stream through the material wall to annular space

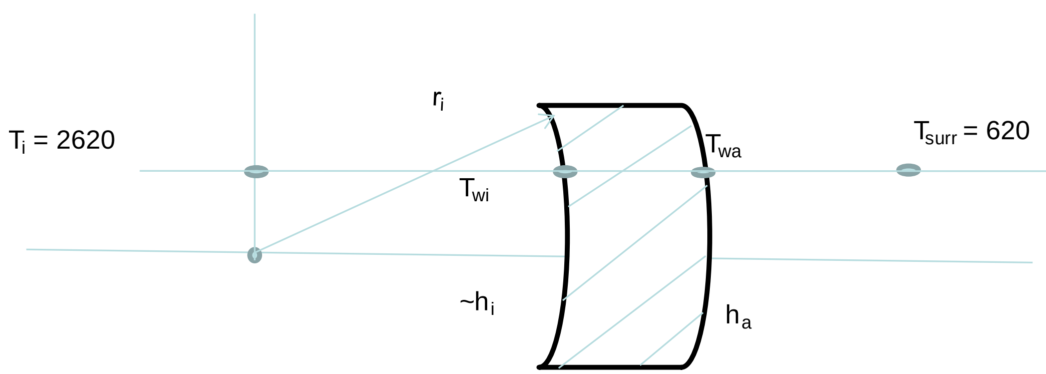


Fig 2. Schematic presentation of the cross-section of combustor liner
- showing prevailing temperatures

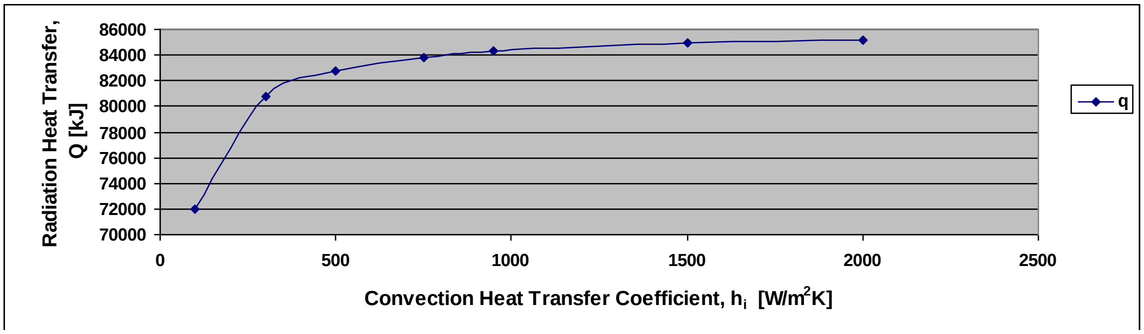


**Fig. 3: Variation of Transferred Heat with Convection Heat Transfer Coefficient**

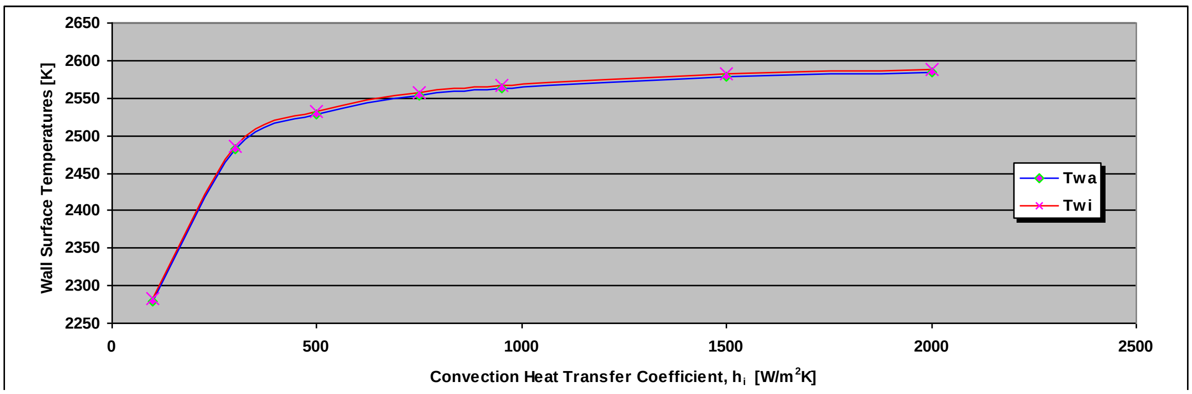


**Fig. 4: Wall Temperatures, $T_{wa}$, $T_{wi}$ versus Convection Heat Transfer Coefficient**

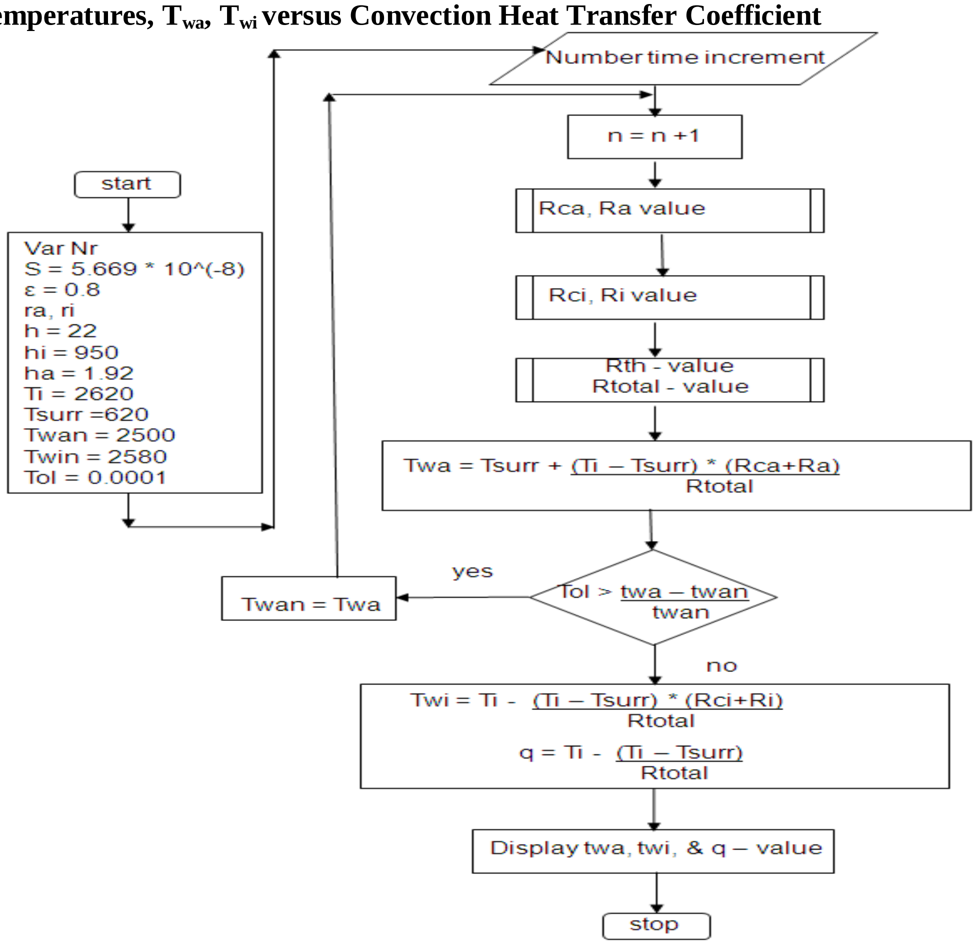


**FIG.5 Flowchart for computing steady-state end-temperatures**

**Appendix 2.** Computer program for the computation of the heat transfer.

```
'Folder      01
    'To calculate STEADY-STATE END TEMPERATURE

    'Private Sub cmdCompute_Click()
    TempCalc()
    Close()
    MsgBox("End of Program")
  End Sub

  Public Function TempCalc()

    Dim VarNr As Integer = 1   'Variant Nr.
    Dim Pi As Double
    Dim ra As Integer = 0    'outer radius
    Dim ri As Integer = 0    'inner radius
    Dim Rac As Double = 0     'Sum outer radiative and convective _
                    thermal resistance
    Dim Rth As Double = 0   'Thermal resistance in material
    Dim Rnconvi As Double = 0  'Inner convective thermal resistanceDim
    Dim Ric As Double = 0   'Sum inner rad./conv. thermal resistance
    Dim Rtotal As Double = 0     'Total thermal resistance
    Dim Twa As Double = 0     'outside surface wall temp.
    Dim Ti As Double = 0      'inner main-stream temp.
    Dim Twi As Double = 0      'inner wall surface temp.
       Dim q(3) As Double       'quantity of heat transferred
    Dim ha As Double = 0     'outside conv. coeff.
    Dim hi As Double = 0     'inner conv.  coeff.
    Dim Tsurr As Double = 0    'Temperature of the surrounding
    Dim Twan As Double = 0 'initially suggested value of Twa
    Dim Twin As Double = 0 'initially suggested value of Twi
    Dim TOL As Double = 0  'Tolerance Test condition
    Dim Twa1 As Double = 0    'interim values of Twa
    Dim FileNumber As Integer = 0
    Dim Output As Object = 0
    Dim d As Double = 0
    Dim ln As Double = 0
    VarNr = CInt(TextBox1.Text)
    FileNumber = 1
    Pi = 3.1416
    ri = 35
    ra = CDbl(TextBox2.Text)
    d = (ra / ri)
    'ln = Math.Log(d)
    ln = 0.007118
    ha = CDbl(TextBox4.Text)
    hi = CDbl(TextBox5.Text)
    Twan = CDbl(TextBox8.Text)
    Twin = CDbl(TextBox9.Text)
    Tsurr = CDbl(TextBox7.Text)
    Ti = CDbl(TextBox6.Text)
    TOL = 0.00001

    For n As Object = 1 To 10 Step 1
```

```
    Rac = 1 / (0.06283 * 35.25 * ha) + 1 / (2.85 * 10 ^ (-9) * 35.25 * _
       (Twan ^ 2 + Tsurr ^ 2) * (Twan + Tsurr))       'correct to ra *
    Rth = ln / (2 * Pi * 22 * 1)

    Rnconvi = 1 / (2 * Pi * 35 * 10 ^ (-2) * hi)
   Ric = Rnconvi + 1 / (1.0 * 10 ^ (-7) *(Ti ^ 2 + Twin ^ 2)*(Ti + Twin))
    Rtotal = Rac + Rth + Ric

      'Program Equation:
      Twa1 = Tsurr + (Ti - Tsurr) * Rac / Rtotal
      If TOL <= (Twa1 - Twan) / Twan Then
      End If
      Twan = Twa1
   Next
   'Else
   Twi = Ti - (Ti - Tsurr) * Ric / Rtotal
   Twa = Twa1
   q(0) = (Ti - Tsurr) / Rtotal
   q(1) = (Ti - Twi) / Ric
   q(2) = (Twi - Twa) / Rth
   q(3) = (Twa - Tsurr) / Rac

   'Print result
   FileOpen(1, "C:\myresultn.txt", OpenMode.Output) 'Open File for Output
   PrintLine(1, TAB(2), ("Date/Time"))
   PrintLine(1, TAB(10), ("01-END TEMP(STEADY STATE): PROGRAM RESULTS"))
   PrintLine(1, ("VarNr, ra,   ri,      Rac,       Rth,       Rnconvi,       Ric,       Rtotal "))
   PrintLine(1, (VarNr), SPC(3), (ra), SPC(2), (ri), SPC(4), (Format(Rac, "0.######")), SPC(4),(Format(Rth,
"0.######")), SPC(4), _    (Format(Rnconvi, "0.######")), SPC(4),(Format(Ric, "0.######")), SPC(4), _
(Format(Rtotal, "0.######")))
   PrintLine(1)
   PrintLine(1, ("Ti  ="), SPC(1), (Format(Ti, "####.0")), SPC(1), ("Tsurr  ="), SPC(1), (Format(Tsurr,
"###.0")), SPC(1), _
   ("Twan = "), SPC(1), (Format(Twan, "###.0")), SPC(1), ("Twin = "), _ SPC(1), (Format(Twin, "####.0")),
SPC(1), ("ha = "), SPC(1), (Format(ha, _ "###.00")), SPC(1), ("hi = "), SPC(1), (Format(hi, "###.0")))

   PrintLine(1, TAB(5), ("END-TEMP VALUES"))
   PrintLine(1, TAB(5), ("================"))
   PrintLine(1, ("Twa"), " Twi", " q(0)", "q(1)", "q(2)", "q(3)")
   PrintLine(1, (Format(Twa, "####.0")), SPC(7), (Format(Twi, "####.0")), SPC(7), (Format(q(0), "#####.0")),
_
         SPC(7), (Format(q(1), "#####.0")), SPC(7), (Format(q(2), "#####.0")), SPC(7), (Format(q(3),
"#####.0")))
   PrintLine(1)
   PrintLine(1)
   TempCalc = 1
  End Function

Private Sub cmdExit_Click()
   'Terminate the Project
   Close()

End
  End Sub
```

End Class
Program Results

```
        2010    Date/Time
        EU406-END TEMP(STEADY STATE): PROGRAM RESULTS    Th = 2.5mm
VarNr, ra,   ri,      Rac,        Rth,       Rnconvi,     Ric,       Rtotal
 18    35    35    0.182265    0.000051    0.002393    0.003104    0.18542

Ti = 2620.0 Tsurr = 620.0 Twan =  2500.0 Twin =  2580.0 ha =  1.92 hi =  950.0
    END-TEMP VALUES
    ================
Twa          Twi         q(0)        q(1)        q(2)        q(3)
2586.0       2586.5      10786.3     10786.3     10786.3     10786.3
```

**APPENDIX3: Tables**

**Table 1: Radiative Transfer heat against convection heat transfer coefficient**

| $h_i$ (W/m$^2$K) | $h_a$ (W/m$^2$K) | Heat transferred, Q (kJ) |
|---|---|---|
| 100 | 20 | 71,948.4 |
| 300 | 20 | 80,755.2 |
| 500 | 20 | 82,781.8 |
| 750 | 20 | 83,833.7 |
| 950 | 20 | 84,284.7 |
| 1500 | 20 | 84,912.7 |
| 2000 | **20** | 85,186.8 |

**Table 2: Internal wall surface temperatures against convection heat transfer coefficient**

| **$h_i$ (W/m$^2$K)** | **$T_{wa}$ (K)** | **$T_{wi}$ (K)** |
|---|---|---|
| 100 | 2,278.9 | 2,282.6 |
| 300 | 2,482.0 | 2,486.1 |
| 500 | 2,528.7 | 2,532.9 |
| 750 | 2,552.9 | 2,557.9 |
| 950 | 2,563.3 | 2,567.7 |
| 1500 | 2,577.8 | 2,582.2 |
| 2000 | 2,584.1 | 2,588.5 |