carbon

December 1, 2016

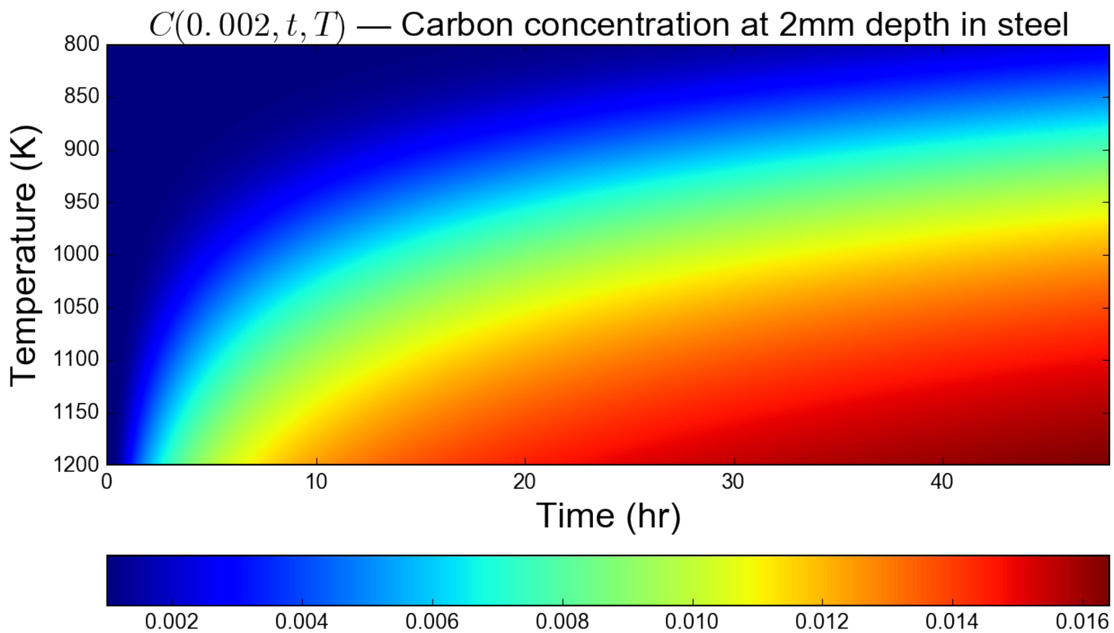
```
In [1]: %pylab inline
        pylab.rcParams['figure.figsize'] = (10, 6)
        matplotlib.rcParams.update({'font.size': 16})
        matplotlib.rcParams.update({'axes.labelsize': 20})
        matplotlib.rcParams.update({'xtick.labelsize': 12})
        matplotlib.rcParams.update({'ytick.labelsize': 12})
        matplotlib.rcParams.update({
                'font.family': 'Helvetica, Arial, sans-serif'
        })

        %config InlineBackend.figure_format = 'retina'
```

```
Populating the interactive namespace from numpy and matplotlib
```

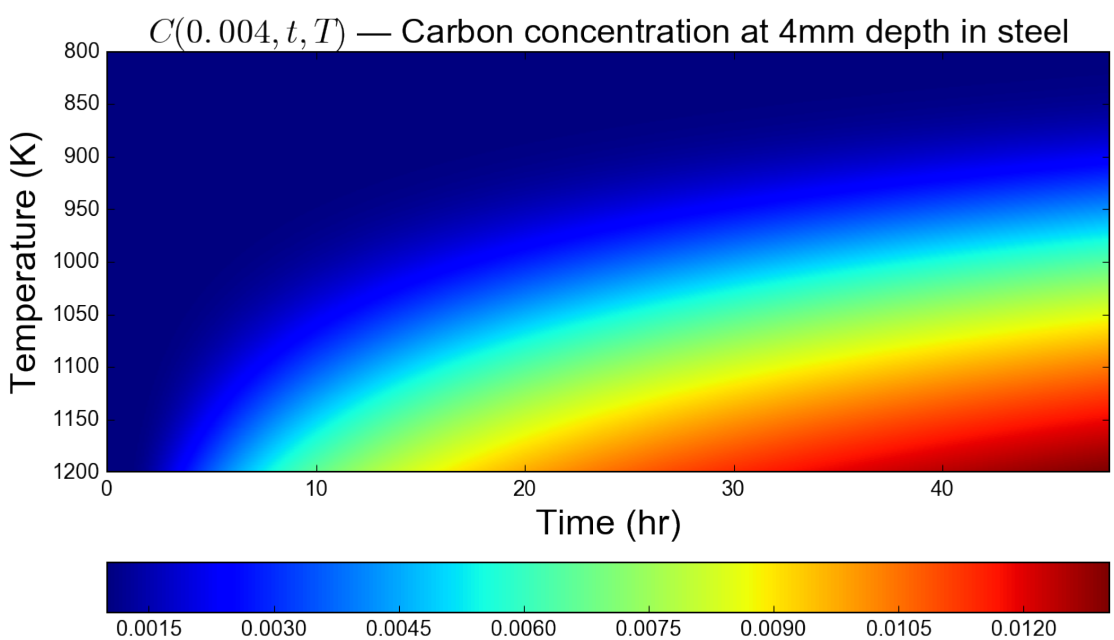
```
In [2]: path = '../data/'
        names = ['C2mm','C4mm','C2mm_800K','C2mm_900K','C2mm_1000K','C2mm_1100K','C
                 'C4mm_800K','C4mm_900K','C4mm_1000K','C4mm_1100K','C4mm_1200K', 't
        v = {}

        v['a'] = pylab.linspace(-4,4,201)
        v['b'] = pylab.linspace(-4,4,101)

        for name in names:
            v[name] = loadtxt(path+name+'.txt')
```

```
In [3]: figure()
        imshow(v['C2mm'], extent=[0,48, 1200, 800], aspect='auto')
        colorbar(orientation='horizontal')
        title('$C(0.002,t,T)$  Carbon concentration at 2mm depth in steel')
        xlabel('Time (hr)')
        ylabel('Temperature (K)')
```

```
Out[3]: <matplotlib.text.Text at 0x10c44e240>
```



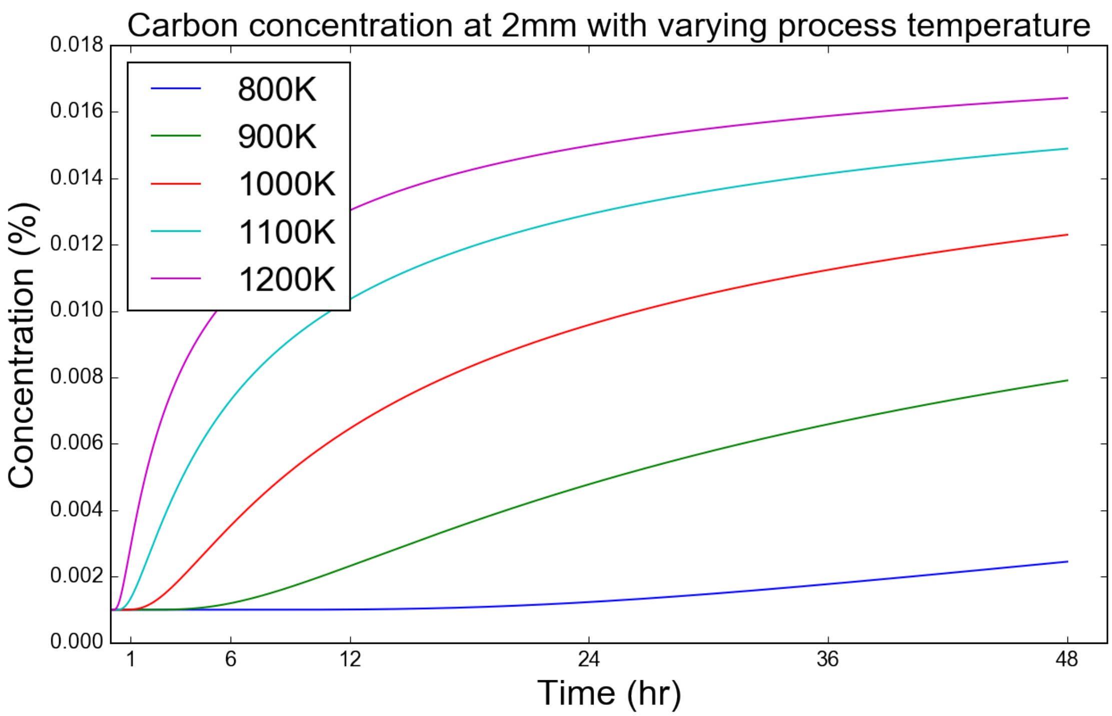

```
In [4]: figure()
        imshow(v['C4mm'], extent=[0,48, 1200, 800], aspect='auto')
        colorbar(orientation='horizontal')
        title('$C(0.004,t,T)$  Carbon concentration at 4mm depth in steel')
        xlabel('Time (hr)')
        ylabel('Temperature (K)')

Out[4]: <matplotlib.text.Text at 0x10c9c0320>
```



These graphs use the `C()` function I implemented in `carbon.cpp` to determine Carbon concentration at a constant depth (2mm and 4mm respectively). The lines parallel to the x-axis represent different carburizing processes, which vary by temperature, and the span of these lines is the procession of time from the start to two days later. It is apparent in both graphs, more prominently in the first one, that higher temperature correlates positively with an increase in concentration by day 2, as well as an increase in the rate of change of concentration. The lesson to carburizing kiln operators is to find an optimization of temperature where carburizing reaches the target concentration fast enough without using too much fuel to maintain higher temperature. However, even the max temperature evaluated, 1200K, is just under 1000řC, a temperature commonly achieved even in common ceramicist's kilns and maintained for long periods of time — and it seems that any increase in fuel expenditure per unit time is overcompensated by foreshortening the time-to-completion in a carburization process with a target at-depth concentration. Another obvious determination from the two graphs is that, at higher depths from the surface of a carburizing steel sample, the increase in carbon concentration is delayed, and thus in the same amount of time, 4mm reaches a lesser concentration than at 2mm. That is to say, there is a negative correlation between depth and concentration at a fixed point in time.

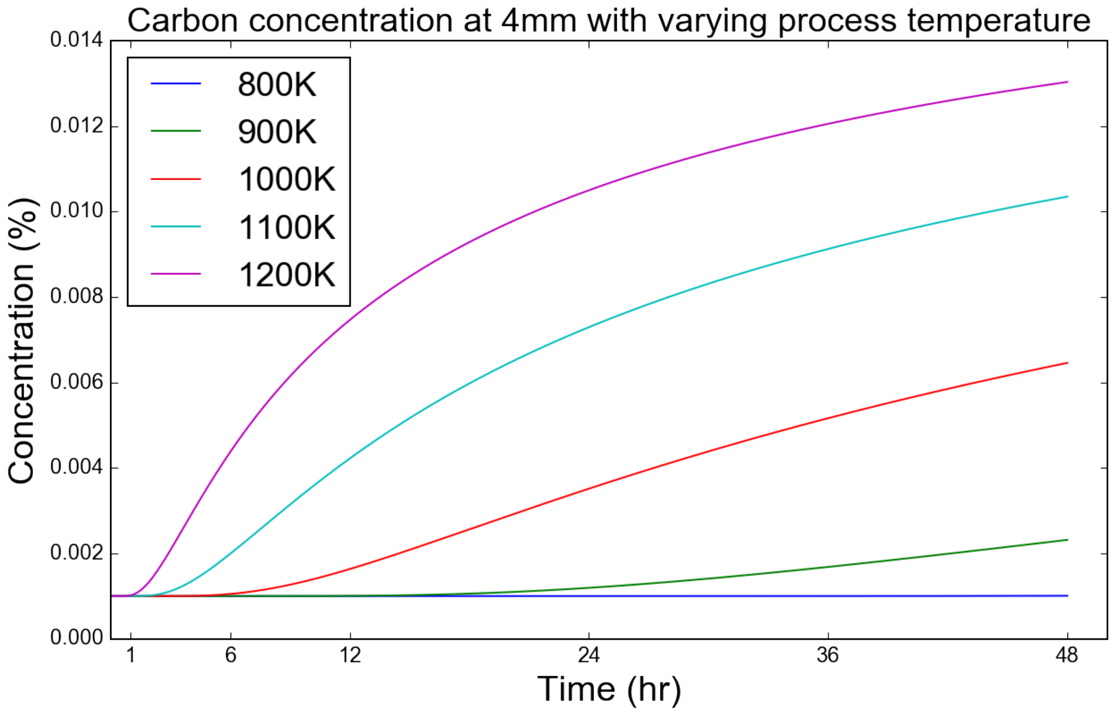
```
In [5]: figure()
        plot(v['time'], v['C2mm_800K'],
             v['time'], v['C2mm_900K'],
             v['time'], v['C2mm_1000K'],
             v['time'], v['C2mm_1100K'],
             v['time'], v['C2mm_1200K'])
        title('Carbon concentration at 2mm with varying process temperature')
        xlabel('Time (hr)')
        ylabel('Concentration (%)')
        legend(['800K','900K','1000K','1100K','1200K'],loc=2)
        xticks( (1*3600, 6*3600, 12*3600, 24*3600, 36*3600, 48*3600),
                ('1', '6', '12', '24', '36', '48') )
```

```
Out[5]: ([<matplotlib.axis.XTick at 0x10ea7df98>,
          <matplotlib.axis.XTick at 0x10ea7db38>,
          <matplotlib.axis.XTick at 0x10f32f588>,
          <matplotlib.axis.XTick at 0x10ead1278>,
          <matplotlib.axis.XTick at 0x10ead1c88>,
          <matplotlib.axis.XTick at 0x10eacf6d8>],
         <a list of 6 Text xticklabel objects>)
```




```
In [6]: figure()
        plot(v['time'], v['C4mm_800K'],
             v['time'], v['C4mm_900K'],
             v['time'], v['C4mm_1000K'],
             v['time'], v['C4mm_1100K'],
             v['time'], v['C4mm_1200K'])
        title('Carbon concentration at 4mm with varying process temperature')
        xlabel('Time (hr)')
        ylabel('Concentration (%)')
        legend(['800K','900K','1000K','1100K','1200K'],loc=2)
        xticks( (1*3600, 6*3600, 12*3600, 24*3600, 36*3600, 48*3600),
                ('1', '6', '12', '24', '36', '48') )
```

```
Out[6]: ([<matplotlib.axis.XTick at 0x10ea5cfd0>,
          <matplotlib.axis.XTick at 0x10f756b38>,
          <matplotlib.axis.XTick at 0x10f33bba8>,
          <matplotlib.axis.XTick at 0x10f7a92e8>,
          <matplotlib.axis.XTick at 0x10f7a9cf8>,
          <matplotlib.axis.XTick at 0x10f7ac748>],
         <a list of 6 Text xticklabel objects>)
```



These graphs reveal that, over time, the concentration at a fixed point increases in an approximately logarithmic fashion at higher temperatures, and a lower temperature carburizing process causes concentration to follow a much shallower, roughly exponential trend. Of course, the function for concentration over time is more complex than this, but it does reveal practical implications in the procession of concentration over time in real-world implementation. Carburizing kiln operators need be aware of a visibly prominent "hump" in higher temperature carburization that is nonexistant in low temperature processes. 900K carburizing will gradually increase in rate of change (henceforth "acceleration"), whereas 1000K carburizing accelerates and then more gradually decelerates. Processes at temperatures greater than 1100K demonstrate very prominent and rapid acceleration in concentration increases throughout the depths of the steel sample, and then rapidly decelerates to a slow, linear pace of concentration change. If the process of carburization involves risks as concentration changes, then it is the responsibility of mill and kiln managers to be very aware of the characteristic slope of the concentration function as it varies over kiln temperature. Of course, these graphs all accomodate only one scenario: that of constant kiln temperature throughout the entire process. Theoretically, in a real-world application, temperature could change deliberately or otherwise for reasons of precision, efficiency, or some combination of the two as the steel approaches a certain concentration at a constant depth. Thus these graphs do not tell the whole story of realistic carburizing processes but do lend some perspective and visualization into how temperature greatly affects the behavior of the process.

```
In [7]:
```