Wellbore heat transfer

Enter table as text with depth, dL, pres and temp

Where is this data coming from?

```r
library(tibble)

well <- "
depth   dL  pres    temp
0         0 200     80.0
334     334 267     83.4
669     334 339     86.9
1003    334 415     90.3
1338    334 495     93.8
1672    334 580     97.2
2007    334 667     100.7
2341    334 756     104.1
2676    334 849     107.6
3010    334 944     111.0
3345    334 1042    114.5
3679    334 1141    117.9
4014    334 1242    121.4
4348    334 1344    124.8
4683    334 1449    128.3
5017    334 1554    131.7
5352    334 1661    135.2
5686    334 1769    138.6
6021    334 1878    142.1
6355    334 1988    145.5
6690    334 2099    149.0
7024    334 2210    152.4
7359    334 2323    155.9
7693    334 2436    159.3
8028    334 2549    162.8
8362    334 2664    166.2
8697    334 2778    169.7
9031    334 2894    173.1
9366    334 3009    176.6
9700    334 3125    180.0
"

# read string text to dataframe
well_table <- read.table(header = TRUE, text = well)
as_tibble(well_table)
#> # A tibble: 30 x 4
#>    depth    dL  pres  temp
#>    <int> <int> <int> <dbl>
#>  1     0     0   200  80
#>  2   334   334   267  83.4
#>  3   669   334   339  86.9
#>  4  1003   334   415  90.3
#>  5  1338   334   495  93.8
```

```
#>  6  1672   334   580  97.2
#>  7  2007   334   667 101.
#>  8  2341   334   756 104.
#>  9  2676   334   849 108.
#> 10  3010   334   944 111
#> # ... with 20 more rows
```

Fluid temperature calculation using old `temp.fluid` function

```
# parameters necessary to calculate the fluid temperature
theta   <-  pi /2
diam.in <- 1.995
diam.ft <- diam.in / 12
tht     <- 80
bht     <- 200
depth   <- 9700
ge      <- (bht - tht) / depth
m <- mass.rate <- 228145
U <-  2
# U <- 4
cp.avg <- (0.53 + 0.5 + 1 ) / 3

# calculate dT/dx for the well
rNodal:::temp.fluid(well_table, theta, depth, bht, tht, U, cp.avg, diam.ft, mass.rate)
#>    depth  dL pres  temp    L       Ti
#> 1      0   0  200  80.0 9700 112.8315
#> 2    334 334  267  83.4 9366 119.1733
#> 3    669 334  339  86.9 9031 125.3442
#> 4   1003 334  415  90.3 8697 131.3225
#> 5   1338 334  495  93.8 8362 137.1017
#> 6   1672 334  580  97.2 8028 142.6617
#> 7   2007 334  667 100.7 7693 147.9966
#> 8   2341 334  756 104.1 7359 153.0885
#> 9   2676 334  849 107.6 7024 157.9328
#> 10  3010 334  944 111.0 6690 162.5143
#> 11  3345 334 1042 114.5 6355 166.8305
#> 12  3679 334 1141 117.9 6021 170.8693
#> 13  4014 334 1242 121.4 5686 174.6310
#> 14  4348 334 1344 124.8 5352 178.1073
#> 15  4683 334 1449 128.3 5017 181.3013
#> 16  5017 334 1554 131.7 4683 184.2090
#> 17  5352 334 1661 135.2 4348 186.8370
#> 18  5686 334 1769 138.6 4014 189.1857
#> 19  6021 334 1878 142.1 3679 191.2652
#> 20  6355 334 1988 145.5 3345 193.0804
#> 21  6690 334 2099 149.0 3010 194.6450
#> 22  7024 334 2210 152.4 2676 195.9686
#> 23  7359 334 2323 155.9 2341 197.0680
#> 24  7693 334 2436 159.3 2007 197.9571
#> 25  8028 334 2549 162.8 1672 198.6558
#> 26  8362 334 2664 166.2 1338 199.1816
#> 27  8697 334 2778 169.7 1003 199.5570
#> 28  9031 334 2894 173.1  669 199.8026
```

```
#> 29  9366 334 3009 176.6  334 199.9425
#> 30  9700 334 3125 180.0    0 200.0000
```

Equation in Prosper manual

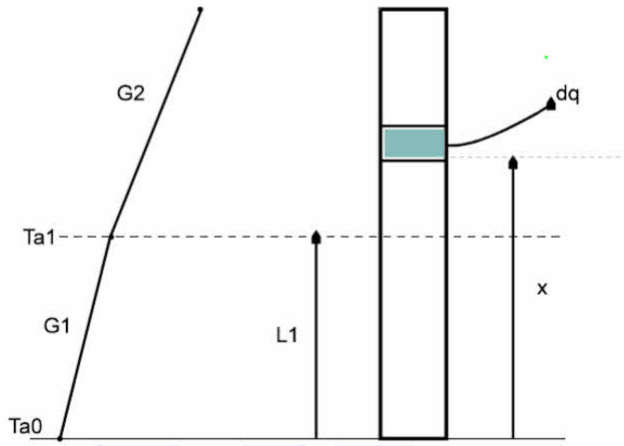
```
# using Prosper equation
U = 8
Cp <- (0.53 + 0.5 + 1 ) / 3
k <- U * pi * diam.ft / m / Cp
Ti <- bht

for (i in nrow(well_table):1) {
    L  <- depth - well_table[i, "depth"]
    dL <- well_table[i, "dL"]
    Tei <- well_table[i, "temp"]
    dT.dx <- k * (Ti - Tei + ge * L * sin(theta))
    Ti <- Ti - dT.dx * dL

    # cat(sprintf("%3d %10.0f %10.2f %12.6f %12.3f \n", i, L, Tei, dT.dx, Ti))
    well_table[i, "L"]  <- L
    well_table[i, "dT.dx"]  <- dT.dx
    well_table[i, "Ti"] <- Ti
}
print(well_table)
#>    depth  dL pres  temp    L        dT.dx       Ti
#> 1      0   0  200  80.0 9700 0.0056746669 169.6644
#> 2    334 334  267  83.4 9366 0.0055207173 169.6644
#> 3    669 334  339  86.9 9031 0.0053622943 171.5083
#> 4   1003 334  415  90.3 8697 0.0052054952 173.2993
#> 5   1338 334  495  93.8 8362 0.0050441966 175.0379
#> 6   1672 334  580  97.2 8028 0.0048844957 176.7227
#> 7   2007 334  667 100.7 7693 0.0047202689 178.3541
#> 8   2341 334  756 104.1 7359 0.0045576130 179.9307
#> 9   2676 334  849 107.6 7024 0.0043904042 181.4529
#> 10  3010 334  944 111.0 6690 0.0042247392 182.9193
#> 11  3345 334 1042 114.5 6355 0.0040544939 184.3304
#> 12  3679 334 1141 117.9 6021 0.0038857646 185.6846
#> 13  4014 334 1242 121.4 5686 0.0037124270 186.9824
#> 14  4348 334 1344 124.8 5352 0.0035405772 188.2224
#> 15  4683 334 1449 128.3 5017 0.0033640907 189.4049
#> 16  5017 334 1554 131.7 4683 0.0031890633 190.5285
#> 17  5352 334 1661 135.2 4348 0.0030093701 191.5937
#> 18  5686 334 1769 138.6 4014 0.0028311069 192.5988
#> 19  6021 334 1878 142.1 3679 0.0026481483 193.5444
#> 20  6355 334 1988 145.5 3345 0.0024665899 194.4289
#> 21  6690 334 2099 149.0 3010 0.0022803061 195.2527
#> 22  7024 334 2210 152.4 2676 0.0020953921 196.0143
#> 23  7359 334 2323 155.9 2341 0.0019057221 196.7142
#> 24  7693 334 2436 159.3 2007 0.0017173910 197.3507
#> 25  8028 334 2549 162.8 1672 0.0015242727 197.9243
#> 26  8362 334 2664 166.2 1338 0.0013324619 198.4334
#> 27  8697 334 2778 169.7 1003 0.0011358322 198.8785
#> 28  9031 334 2894 173.1  669 0.0009404779 199.2578
```

728 PROSPER

2.16.2.3.1 Rough Approximation Temperature Model



$$T_a(x) = T_{a1} - G_2(x - L_1)\cos\theta$$

$$\frac{dT}{dx} = -\frac{U\pi D}{\dot{m}\,\bar{C}_p}\left[T - T_{a1} + G_2(x - L_1)\cos\theta\right]$$

Where:

T_{a1} = Ambient temperature at L_1

T = Average fluid temperature in the segment.

θ = Deviation angle

$\dot{m}$ = Fluid mass flow rate

C_p = Weighted average specific heat capacity for all the phases

U = Overall heat transfer coefficient referred to pipe inside diameter

D = Pipe inside diameter

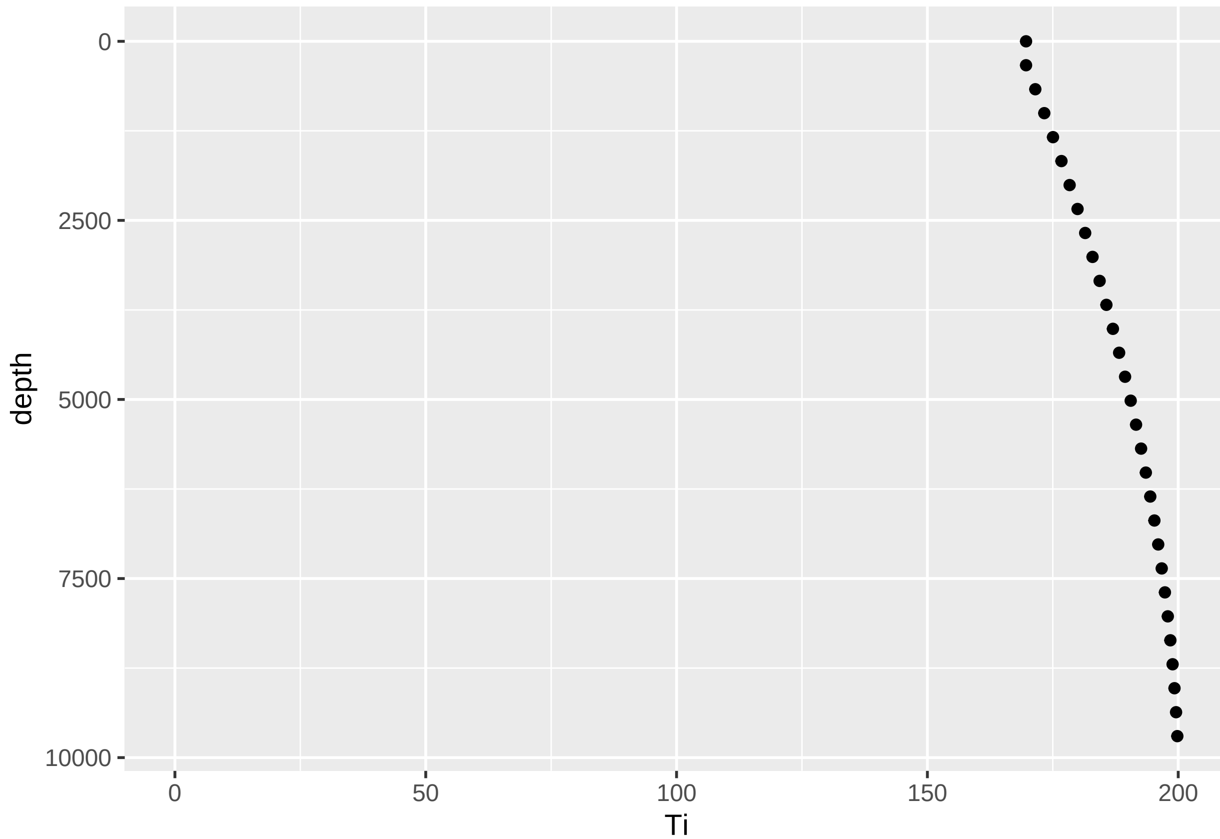
G = Geothermal gradient

Figure 1: Prosper Rough Approximation

```
#> 29  9366 334 3009 176.6  334 0.0007402724 199.5720
#> 30  9700 334 3125 180.0    0 0.0005413097 199.8192

library(ggplot2)

ggplot(well_table, aes(x = Ti, y = depth)) +
    geom_point() + scale_y_continuous(trans = "reverse") +
    scale_x_continuous(lim = c(0, 200))
```



Ramey's derivation from Alves equation

Using the momentum balance from Eq. 2 results in

$$\Phi=\left(\frac{\tau\pi d}{A_p}\right)\Big/\frac{dp}{dL}. \qquad (39)$$

If friction is neglected, $\Phi=0$, and Eq. 18 reduces to

$$\boxed{\begin{aligned}T=&(T_{ei}-g_eL\sin\theta)+(T_i-T_{ei})\exp(-L/A)+g_eA\sin\theta\\&\times[1-\exp(-L/A)], \qquad (40)\end{aligned}}$$

which is the Ramey expression for incompressible liquid flow.

A comparison of Eqs. 18 and 40 shows that the proposed gener-

```
# using Ramey's equation
U <- 4
Cp <- (0.53 + 0.5 + 1) / 3
k <- U * pi * diam.ft / m / Cp
A <- 1 / k                          # relaxation distance by Ramey. Shoham, pg 297

Ti <- bht
for (i in nrow(well_table):1) {
    L <- depth - well_table[i, "depth"]
    Tei <- well_table[i, "temp"]
    Ti <- (Tei - ge * L * sin(theta)) +
          (Ti - Tei) * exp(-L/A) +
        ge * A * sin(theta) * (1 - exp(-L/A))

    # cat(sprintf("%3d %10.0f %10.2f \n", i, L, Ti))
    well_table[i, "L"]  <- L
    well_table[i, "Ti"] <- Ti
}
print(well_table)
#>    depth  dL pres  temp    L        dT.dx        Ti
#> 1      0   0  200  80.0 9700 0.0056746669  72.15043
#> 2    334 334  267  83.4 9366 0.0055207173  79.64980
#> 3    669 334  339  86.9 9031 0.0053622943  87.13703
#> 4   1003 334  415  90.3 8697 0.0052054952  94.57754
#> 5   1338 334  495  93.8 8362 0.0050441966 101.96269
#> 6   1672 334  580  97.2 8028 0.0048844957 109.25465
#> 7   2007 334  667 100.7 7693 0.0047202689 116.44005
#> 8   2341 334  756 104.1 7359 0.0045576130 123.47868
#> 9   2676 334  849 107.6 7024 0.0043904042 130.35361
#> 10  3010 334  944 111.0 6690 0.0042247392 137.02369
#> 11  3345 334 1042 114.5 6355 0.0040544939 143.47008
#> 12  3679 334 1141 117.9 6021 0.0038857646 149.65263
```

```
#> 13  4014 334 1242 121.4 5686 0.0037124270 155.55278
#> 14  4348 334 1344 124.8 5352 0.0035405772 161.13373
#> 15  4683 334 1449 128.3 5017 0.0033640907 166.37961
#> 16  5017 334 1554 131.7 4683 0.0031890633 171.25955
#> 17  5352 334 1661 135.2 4348 0.0030093701 175.76292
#> 18  5686 334 1769 138.6 4014 0.0028311069 179.86725
#> 19  6021 334 1878 142.1 3679 0.0026481483 183.56947
#> 20  6355 334 1988 145.5 3345 0.0024665899 186.85767
#> 21  6690 334 2099 149.0 3010 0.0022803061 189.73819
#> 22  7024 334 2210 152.4 2676 0.0020953921 192.21117
#> 23  7359 334 2323 155.9 2341 0.0019057221 194.29340
#> 24  7693 334 2436 159.3 2007 0.0017173910 195.99772
#> 25  8028 334 2549 162.8 1672 0.0015242727 197.35145
#> 26  8362 334 2664 166.2 1338 0.0013324619 198.37972
#> 27  8697 334 2778 169.7 1003 0.0011358322 199.11938
#> 28  9031 334 2894 173.1  669 0.0009404779 199.60639
#> 29  9366 334 3009 176.6  334 0.0007402724 199.88515
#> 30  9700 334 3125 180.0    0 0.0005413097 200.00000

library(ggplot2)

ggplot(well_table, aes(x = Ti, y = depth)) +
    geom_point() + scale_y_continuous(trans = "reverse") +
    scale_x_continuous(lim = c(0, 200))
```