Cannabis Brownie Kinetics

$CBDA \xrightarrow{k1} CBD \xrightarrow{k2} THC$

$THCA \xrightarrow{k3} THC \xrightarrow{k4} CBN$

or

$A \xrightarrow{k1} B \xrightarrow{k2} D$

$C \xrightarrow{k3} D \xrightarrow{k4} E$

Estimated initial 9.1 mM CBDA + 1.1 mM THCA averaged from various strains

Assumed decarboxylation (k1 & k3) and degradation (k2 & k4) reactions are elementary and follow the Arrhenius equation with constants below

In[5335]:=
```
Grid[{
  {"Rate Constant", "A [s^-1]", "E_a [kJ/mol]"},
  {"k1", 1.9*^12, 112},
  {"k2", 9.5*^2, 52},
  {"k3", 1.0*^9, 86},
  {"k4", 1.2*^6, 77}
 }
 , Frame → All]
```

Out[5335]=

Rate Constant	A $[s^{-1}]$	E_a [kJ/mol]
k1	1.9×10^{12}	112
k2	950.	52
k3	$1. \times 10^{9}$	86
k4	1.2×10^{6}	77

In[5382]:=
```
ca0 = 9.1; (*mM CBDA*)
cb0 = 0;  (*mM CBD*)
cc0 = 1.1; (*mM THCA*)
cd0 = 0; (*mM THC*)
ce0 = 0;  (*mM CBN*)
```

$$cacstr := \frac{ca0}{1 + 60\,t\,k1cstr};$$

$$cbcstr := \frac{cb0 + 60\,t\,k1cstr\,cacstr}{1 + 60\,t\,k2cstr};$$

$$cccstr := \frac{cc0}{1 + 60\,t\,k3cstr};$$

$$cdcstr := \frac{cd0 + 60\,t\,k2cstr\,cbcstr + 60\,t\,k3cstr\,cccstr}{1 + 60\,t\,k4cstr};$$

$$cecstr := ca0 + cb0 + cc0 + cd0 + ce0 - cacstr - cbcstr - cccstr - cdcstr;$$

$$\text{ca0new} := \frac{\text{ca0}}{1 + 60\ \text{taucstr}\ \text{k1cstr}};$$

$$\text{cb0new} := \frac{\text{cb0} + 60\ \text{taucstr}\ \text{k1cstr}\ \text{ca0new}}{1 + 60\ \text{taucstr}\ \text{k2cstr}};$$

$$\text{cc0new} := \frac{\text{cc0}}{1 + 60\ \text{taucstr}\ \text{k3cstr}};$$

$$\text{cd0new} := \left(\text{cd0} + 60\ \text{taucstr}\ \text{k2cstr}\ \text{cb0new} + 60\ \text{taucstr}\ \text{k3cstr}\ \text{cc0new}\right) \big/ \left(1 + 60\ \text{taucstr}\ \text{k4cstr}\right);$$

$$\text{ce0new} := \text{ca0} + \text{cb0} + \text{cc0} + \text{cd0} + \text{ce0} - \text{ca0new} - \text{cb0new} - \text{cc0new} - \text{cd0new};$$

$$\text{capfr} := \text{ca0new}\ \text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k1pfr}\right];$$

$$\text{cbpfr} := \frac{\text{k1pfr}}{\text{k2pfr} - \text{k1pfr}}\ \text{capfr} + \frac{\text{cb0new}\ (\text{k2pfr} - \text{k1pfr}) - \text{k1pfr}\ \text{ca0new}}{\text{k2pfr} - \text{k1pfr}}\ \text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k2pfr}\right];$$

$$\text{ccpfr} := \text{cc0new}\ \text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k3pfr}\right];$$

$$\text{vara} := \frac{\text{k1pfr}\ \text{k2pfr}\ \text{ca0new}}{\text{k2pfr} - \text{k1pfr}};$$

$$\text{varb} := \frac{\text{k2pfr}\ \left(\text{cb0new}\ (\text{k2pfr} - \text{k1pfr}) - \text{k1pfr}\ \text{ca0new}\right)}{\text{k2pfr} - \text{k1pfr}};$$

$$\text{varc} := \text{k3pfr}\ \text{cc0new};$$

$$\begin{aligned}\text{cdpfr} := &\frac{1}{\text{k4pfr} - \text{k1pfr}}\ \text{vara}\ \left(\text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k1pfr}\right] - \text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k4pfr}\right]\right) + \\ &\frac{1}{\text{k4pfr} - \text{k2pfr}}\ \text{varb}\ \left(\text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k2pfr}\right] - \text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k4pfr}\right]\right) + \\ &\frac{1}{\text{k4pfr} - \text{k3pfr}}\ \text{varc}\ \left(\text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k3pfr}\right] - \text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k4pfr}\right]\right) + \\ &\text{cd0new}\ \text{Exp}\left[-60\ (\text{t} - \text{taucstr})\ \text{k4pfr}\right];\end{aligned}$$

$$\text{cepfr} := \text{ca0} + \text{cb0} + \text{cc0} + \text{cd0} + \text{ce0} - \text{capfr} - \text{cbpfr} - \text{ccpfr} - \text{cdpfr};$$

$$\text{k1cstr} := 1.9 * 10^{12}\ \text{Exp}\left[\frac{-112}{8.314 * 10^{-3}\ \frac{\text{tempcstr}+459.67}{9/5}}\right];$$

$$\text{k2cstr} := 9.5 * 10^{2}\ \text{Exp}\left[\frac{-52}{8.314 * 10^{-3}\ \frac{\text{tempcstr}+459.67}{9/5}}\right];$$

$$\text{k3cstr} := 1.0 * 10^{9}\ \text{Exp}\left[\frac{-86}{8.314 * 10^{-3}\ \frac{\text{tempcstr}+459.67}{9/5}}\right];$$

$$\text{k4cstr} := 1.2 * 10^{6}\ \text{Exp}\left[\frac{-77}{8.314 * 10^{-3}\ \frac{\text{tempcstr}+459.67}{9/5}}\right];$$

$$\text{k1pfr} := 1.9 * 10^{12}\ \text{Exp}\left[\frac{-112}{8.314 * 10^{-3}\ \frac{\text{temppfr}+459.67}{9/5}}\right];$$

$$\text{k2pfr} := 9.5 * 10^{2}\ \text{Exp}\left[\frac{-52}{8.314 * 10^{-3}\ \frac{\text{temppfr}+459.67}{9/5}}\right];$$

$$\text{k3pfr} := 1.0 * 10^{9}\ \text{Exp}\left[\frac{-86}{8.314 * 10^{-3}\ \frac{\text{temppfr}+459.67}{9/5}}\right];$$

```
k4pfr := 1.2 * 10^6 Exp[-77 / (8.314 * 10^-3 (temppfr+459.67)/(9/5))];

p[t_, left_, right_] := HeavisideTheta[t - left] HeavisideTheta[right - t];
line1 := Line[{{taucstr, 0}, {taucstr, ca0 + cb0 + cc0 + cd0 + ce0}}];
line2 := Line[{{taucstr + taupfr, 0}, {taucstr + taupfr, ca0 + cb0 + cc0 + cd0 + ce0}}];

Manipulate[
 tempcstr;
 temppfr;
 Plot[{
   cacstr p[t, 0, taucstr],
   cbcstr p[t, 0, taucstr],
   cccstr p[t, 0, taucstr],
   cdcstr p[t, 0, taucstr],
   cecstr p[t, 0, taucstr],
   capfr p[t, taucstr, taucstr + taupfr],
   cbpfr p[t, taucstr, taucstr + taupfr],
   ccpfr p[t, taucstr, taucstr + taupfr],
   cdpfr p[t, taucstr, taucstr + taupfr],
   cepfr p[t, taucstr, taucstr + taupfr]
  }, {t, 0, taucstr + taupfr},
  Epilog → {line1, line2},
  PlotStyle → {Red, Orange, Yellow, Green, Blue},
  PlotLabel → "Series CSTR + PFR Concentrations",
  AxesLabel → {"Time [min]", "Concentration [mM]"},
  PlotLegends → {"CBDA", "CBD", "THCA", "THC", "CBN"},
  PlotRange → {0, ca0 + cb0 + cc0 + cd0 + ce0}],
 {{tempcstr, 240, "CSTR Temp [oF]"}, 70, 500, Appearance → "Labeled"},
 {{taucstr, 30, "CSTR τ [min]"}, 0, 5000, Appearance → "Labeled"},
 {{temppfr, 300, "PFR Temp [oF]"}, 70, 500, Appearance → "Labeled"},
 {{taupfr, 30, "PFR τ [min]"}, 0, 5000, Appearance → "Labeled"},
 LocalizeVariables → False]
```

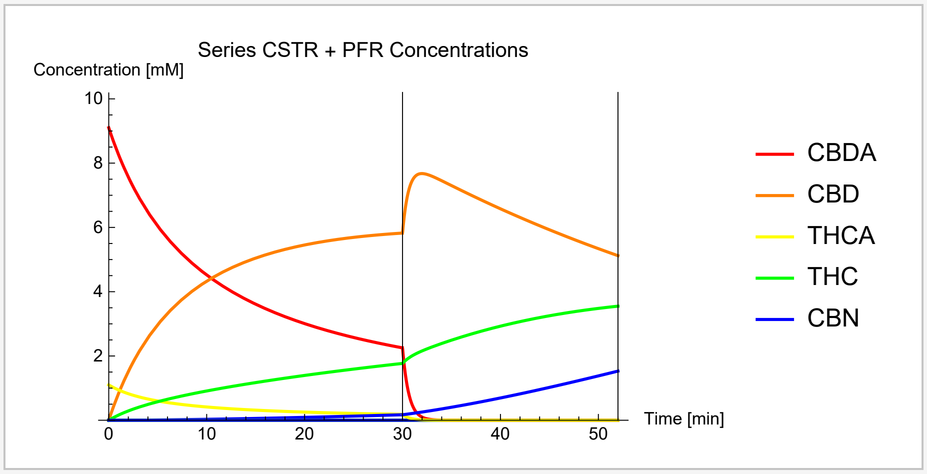
CSTR Temp [oF] 240

CSTR τ [min] 30.

PFR Temp [oF] 300.

PFR τ [min] 22

Out[5414]=



Setting PFR time and temp to recipe-specific 22 min and 212 oF, CSTR time and temp can be optimized for final THC concentration

```
ca0 = 9.1; (*mM CBDA*)
cb0 = 0;  (*mM CBD*)
cc0 = 1.1; (*mM THCA*)
cd0 = 0; (*mM THC*)
ce0 = 0;  (*mM CBN*)

ca0new := ca0 / (1 + 60 taucstr k1cstr);
cb0new := (cb0 + 60 taucstr k1cstr ca0new) / (1 + 60 taucstr k2cstr);
cc0new := cc0 / (1 + 60 taucstr k3cstr);
cd0new := (cd0 + 60 taucstr k2cstr cb0new + 60 taucstr k3cstr cc0new) / (1 + 60 taucstr k4cstr);
ce0new := ca0 + cb0 + cc0 + cd0 + ce0 - ca0new - cb0new - cc0new - cd0new;

capfr := ca0new Exp[-60 taupfr k1pfr];
cbpfr := k1pfr / (k2pfr - k1pfr) capfr + (cb0new (k2pfr - k1pfr) - k1pfr ca0new) / (k2pfr - k1pfr) Exp[-60 taupfr k2pfr];
ccpfr := cc0new Exp[-60 taupfr k3pfr];
    vara := k1pfr k2pfr ca0new / (k2pfr - k1pfr);
    varb := k2pfr (cb0new (k2pfr - k1pfr) - k1pfr ca0new) / (k2pfr - k1pfr);
```

$$\text{varc} := \text{k3pfr cc0new};$$

$$\text{cdpfr} := \frac{\text{vara}\left(\text{Exp}[-60\ \text{taupfr k1pfr}] - \text{Exp}[-60\ \text{taupfr k4pfr}]\right)}{\text{k4pfr} - \text{k1pfr}} + \frac{1}{\text{k4pfr} - \text{k2pfr}}\text{varb}\left(\text{Exp}[-60\ \text{taupfr k2pfr}] - \text{Exp}[-60\ \text{taupfr k4pfr}]\right) + \frac{1}{\text{k4pfr} - \text{k3pfr}}\text{varc}\left(\text{Exp}[-60\ \text{taupfr k3pfr}] - \text{Exp}[-60\ \text{taupfr k4pfr}]\right) + \text{cd0new Exp}[-60\ \text{taupfr k4pfr}];$$

$$\text{cepfr} := \text{ca0} + \text{cb0} + \text{cc0} + \text{cd0} + \text{ce0} - \text{capfr} - \text{cbpfr} - \text{ccpfr} - \text{cdpfr};$$

$$\text{k1cstr} := 1.9 * 10^{12}\ \text{Exp}\left[\frac{-112}{8.314 * 10^{-3}\ \frac{\text{tempcstr}+459.67}{9/5}}\right];$$

$$\text{k2cstr} := 9.5 * 10^{2}\ \text{Exp}\left[\frac{-52}{8.314 * 10^{-3}\ \frac{\text{tempcstr}+459.67}{9/5}}\right];$$

$$\text{k3cstr} := 1.0 * 10^{9}\ \text{Exp}\left[\frac{-86}{8.314 * 10^{-3}\ \frac{\text{tempcstr}+459.67}{9/5}}\right];$$

$$\text{k4cstr} := 1.2 * 10^{6}\ \text{Exp}\left[\frac{-77}{8.314 * 10^{-3}\ \frac{\text{tempcstr}+459.67}{9/5}}\right];$$

$$\text{k1pfr} := 1.9 * 10^{12}\ \text{Exp}\left[\frac{-112}{8.314 * 10^{-3}\ \frac{\text{temppfr}+459.67}{9/5}}\right];$$

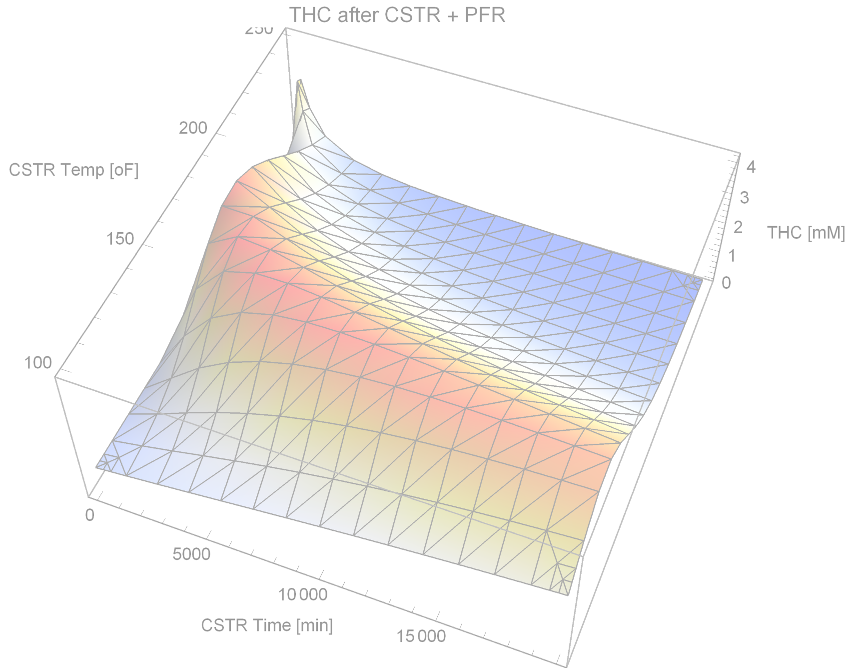
$$\text{k2pfr} := 9.5 * 10^{2}\ \text{Exp}\left[\frac{-52}{8.314 * 10^{-3}\ \frac{\text{temppfr}+459.67}{9/5}}\right];$$

$$\text{k3pfr} := 1.0 * 10^{9}\ \text{Exp}\left[\frac{-86}{8.314 * 10^{-3}\ \frac{\text{temppfr}+459.67}{9/5}}\right];$$

$$\text{k4pfr} := 1.2 * 10^{6}\ \text{Exp}\left[\frac{-77}{8.314 * 10^{-3}\ \frac{\text{temppfr}+459.67}{9/5}}\right];$$

```
temppfr = 212;
taupfr = 22;

Plot3D[{cdpfr(*,4.05*)},
 {taucstr, 0, 20000}, {tempcstr, 100, 250},
 PlotRange → Automatic,
 AxesLabel → {"CSTR Time [min]", "CSTR Temp [oF]", "THC [mM]"},
 PlotLabel → "THC after CSTR + PFR",
 ColorFunction → ColorData["TemperatureMap"],
 Mesh → All]
```

Out[404]=



Optimization

CSTR time [min] and temp [oF] could not be optimized for CBD because concentration diverged with infinite temp for 0 time.

THC concentration is maximized at 0.264232 mM (post-16x dilution in the PFR) for time [min] and temp [oF] below

```
ca0 = 9.1; (*mM CBDA*)
cb0 = 0; (*CBD*)
cc0 = 1.1; (*mM THCA*)
cd0 = 0; (*THC*)
ce0 = 0; (*CBN*)
```

$$(*k1cstr:=1.9*10^{12}Exp\left[\frac{-112}{8.314*10^{-3}\frac{tempcstr+459.67}{9/5}}\right];$$

$$k2cstr:=9.5*10^{2}Exp\left[\frac{-52}{8.314*10^{-3}\frac{tempcstr+459.67}{9/5}}\right];$$

$$k3cstr:=1.0*10^{9}Exp\left[\frac{-86}{8.314*10^{-3}\frac{tempcstr+459.67}{9/5}}\right];$$

$$k4cstr:=1.2*10^{6}Exp\left[\frac{-77}{8.314*10^{-3}\frac{tempcstr+459.67}{9/5}}\right];*)$$

$$k1cstrop := 1.9*10^{12}\ Exp\left[\frac{-112}{8.314*10^{-3}\ \frac{tempcstrop+459.67}{9/5}}\right];$$

$$k2cstrop := 9.5*10^{2}\ Exp\left[\frac{-52}{8.314*10^{-3}\ \frac{tempcstrop+459.67}{9/5}}\right];$$

$$k3cstrop := 1.0 * 10^{9}\ \mathrm{Exp}\left[\frac{-86}{8.314 * 10^{-3}\ \frac{tempcstrop+459.67}{9/5}}\right];$$

$$k4cstrop := 1.2 * 10^{6}\ \mathrm{Exp}\left[\frac{-77}{8.314 * 10^{-3}\ \frac{tempcstrop+459.67}{9/5}}\right];$$

$$k1pfr := 1.9 * 10^{12}\ \mathrm{Exp}\left[\frac{-112}{8.314 * 10^{-3}\ \frac{temppfr+459.67}{9/5}}\right];$$

$$k2pfr := 9.5 * 10^{2}\ \mathrm{Exp}\left[\frac{-52}{8.314 * 10^{-3}\ \frac{temppfr+459.67}{9/5}}\right];$$

$$k3pfr := 1.0 * 10^{9}\ \mathrm{Exp}\left[\frac{-86}{8.314 * 10^{-3}\ \frac{temppfr+459.67}{9/5}}\right];$$

$$k4pfr := 1.2 * 10^{6}\ \mathrm{Exp}\left[\frac{-77}{8.314 * 10^{-3}\ \frac{temppfr+459.67}{9/5}}\right];$$

$$ca0new := \frac{ca0}{1 + 60\ taucstrop\ k1cstrop};$$

$$cb0new := \frac{cb0 + 60\ taucstrop\ k1cstrop\ ca0new}{1 + 60\ taucstrop\ k2cstrop};$$

$$cc0new := \frac{cc0}{1 + 60\ taucstrop\ k3cstrop};$$

$$cd0new := (cd0 + 60\ taucstrop\ k2cstrop\ cb0new + 60\ taucstrop\ k3cstrop\ cc0new) \Big/ (1 + 60\ taucstrop\ k4cstrop);$$

$$ce0new := ca0 + cb0 + cc0 + cd0 + ce0 - ca0new - cb0new - cc0new - cd0new;$$

$$ca0newmax := \frac{ca0}{1 + 60\ taucstrmax\ k1cstrop};$$

$$cb0newmax := \frac{cb0 + 60\ taucstrmax\ k1cstrop\ ca0newmax}{1 + 60\ taucstrmax\ k2cstrop};$$

$$cc0newmax := \frac{cc0}{1 + 60\ taucstrmax\ k3cstrop};$$

$$cd0newmax := (cd0 + 60\ taucstrmax\ k2cstrop\ cb0newmax + 60\ taucstrmax\ k3cstrop\ cc0newmax) \Big/ (1 + 60\ taucstrmax\ k4cstrop);$$

$$ce0newmax := ca0 + cb0 + cc0 + cd0 + ce0 - ca0newmax - cb0newmax - cc0newmax - cd0newmax;$$

```
temppfr = 212;
taupfr = 22;

capfr := ca0new Exp[-60 taupfr k1pfr];
```

$$cbpfr := \frac{k1pfr}{k2pfr - k1pfr}\ capfr + \frac{cb0new\ (k2pfr - k1pfr) - k1pfr\ ca0new}{k2pfr - k1pfr}\ \mathrm{Exp}[-60\ taupfr\ k2pfr];$$

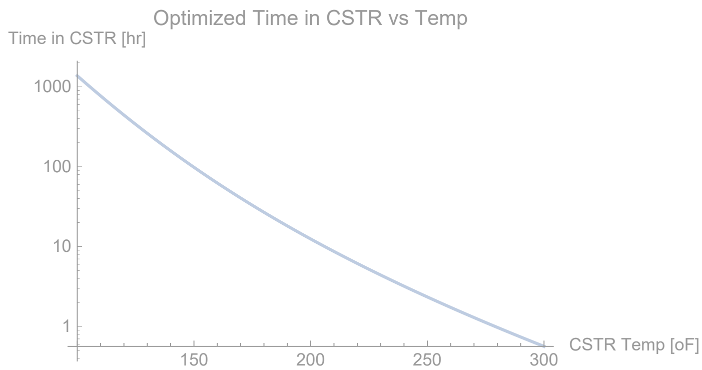
```
ccpfr := cc0new Exp[-60 taupfr k3pfr];
```

$$vara := \frac{k1pfr\ k2pfr\ ca0new}{k2pfr - k1pfr};$$

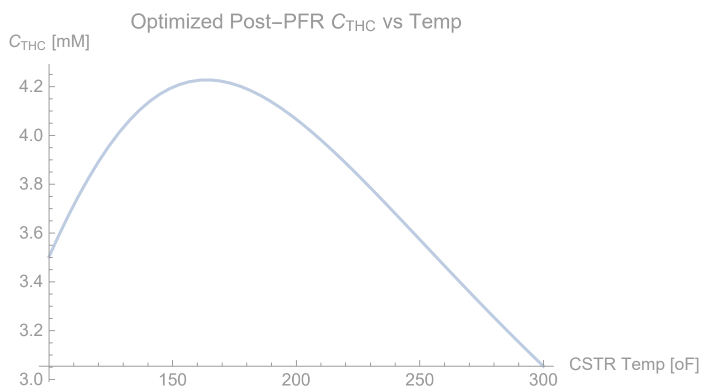
```
    varb := (k2pfr (cb0new (k2pfr - k1pfr) - k1pfr ca0new))/(k2pfr - k1pfr);
    varc := k3pfr cc0new;
cdpfr := 1/(k4pfr - k1pfr) vara (Exp[-60 taupfr k1pfr] - Exp[-60 taupfr k4pfr]) +
   1/(k4pfr - k2pfr) varb (Exp[-60 taupfr k2pfr] - Exp[-60 taupfr k4pfr]) + 1/(k4pfr - k3pfr) varc
    (Exp[-60 taupfr k3pfr] - Exp[-60 taupfr k4pfr]) + cd0new Exp[-60 taupfr k4pfr];
cepfr := ca0 + cb0 + cc0 + cd0 + ce0 - capfr - cbpfr - ccpfr - cdpfr;

capfrmax := ca0newmax Exp[-60 taupfr k1pfr];
cbpfrmax :=
  k1pfr/(k2pfr - k1pfr) capfrmax + (cb0newmax (k2pfr - k1pfr) - k1pfr ca0newmax)/(k2pfr - k1pfr) Exp[-60 taupfr k2pfr];
ccpfrmax := cc0newmax Exp[-60 taupfr k3pfr];
    varamax := (k1pfr k2pfr ca0newmax)/(k2pfr - k1pfr);
    varbmax := (k2pfr (cb0newmax (k2pfr - k1pfr) - k1pfr ca0newmax))/(k2pfr - k1pfr);
    varcmax := k3pfr cc0newmax;
cdpfrmax := 1/(k4pfr - k1pfr) varamax (Exp[-60 taupfr k1pfr] - Exp[-60 taupfr k4pfr]) +
   1/(k4pfr - k2pfr) varbmax (Exp[-60 taupfr k2pfr] - Exp[-60 taupfr k4pfr]) +
   1/(k4pfr - k3pfr) varcmax (Exp[-60 taupfr k3pfr] - Exp[-60 taupfr k4pfr]) +
   cd0newmax Exp[-60 taupfr k4pfr];
cepfrmax := ca0 + cb0 + cc0 + cd0 + ce0 - capfrmax - cbpfrmax - ccpfrmax - cdpfrmax;

(*4.2277190685 mM before dilution*)
NArgMax[{cdpfr, taucstrop ≥ 0, tempcstrop ≥ 0}, {taucstrop, tempcstrop}]

taucstrmax := NArgMax[{cdpfr, taucstrop ≥ 0}, taucstrop];

LogPlot[taucstrmax/60,
 {tempcstrop, 100, 300},
 PlotLabel → "Optimized Time in CSTR vs Temp",
 AxesLabel → {"CSTR Temp [oF]", "Time in CSTR [hr]"},
 MaxRecursion → 0]

Plot[cdpfrmax,
 {tempcstrop, 100, 300},
 PlotRange → All,
 PlotLabel → "Optimized Post-PFR C_THC vs Temp",
 AxesLabel → {"CSTR Temp [oF]", "C_THC [mM]"},
 MaxRecursion → 0]
```

Out[5378]= {3182.09, 163.718}

Out[5380]=



Out[5381]=



Final Concentrations (Diluted 16x)

```
Grid[{
  {"Compound", "CBDA", "CBD", "THCA", "THC", "CBN"},
  {"Label", "CA", "CB", "CC", "CD", "CE"},
  {"Initial Conc [mM]", 9.1, 0, 1.1, 0, 0},
  {"Final Conc [mM]", 0.989/16, 2.619/16, 0.0159/16, 4.227/16, 2.349/16}
 }
 , Frame → All]
```

Compound	CBDA	CBD	THCA	THC	CBN
Label	CA	CB	CC	CD	CE
Initial Conc [mM]	9.1	0	1.1	0	0
Final Conc [mM]	0.0618125	0.163688	0.00099375	0.264188	0.146813

Reactor Calculations

THC = 4.227719069 mM at 163.72 oF for 3182 min ≈ 53 hr ≈ 2.2 days

CBD concentration max at ∞ temp for 0 time

13x9x1 in^3 pan has a surface area to volume ratio of 2.376

A pipe matching this would have diameter 3.025 in

For 1 in thick brownies to be produced every 1 s, volumetric flow rate would be

$\pi * (3.025/2)^2\ 1$ = 7.187 in^3/s = 424 L/hr

Including the 16x dilution from CSTR to PFR, 26.5 L oil/hr required

424 L/hr brownie mix * 22 min = 155.467 L = 9487 in^3

PFR length = $V/(\pi\,(D/2)^2)$ = 1320 in = 110 ft long PFR

1 oz cannabis / 13*9*1 in^3 batch = 1.74 g / brownie

26.5 L/hr for 53 hrs → 1404 L CSTR

Reactor calculations hidden above

Batch SA/V ratio = 2.376

Match PFR → 3” diam

1” thick brownie per second (1.75 g ea) → 424 L/hr

22 min → 155 L PFR (110’ long)

16x dilution → 27 L/hr

2.2 days → 1400 L CSTR

THC = 4.2 mM at 163.72 oF

Wholesale $1400 / lb

14 lb / hr

Costs $20,000 / hr

Sold for $20 ea → $72,000 / hr revenue

Expenditure

Prices

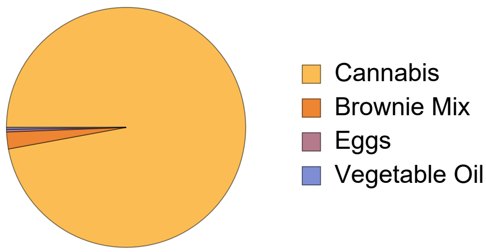
- 1 oz cannabis / 0.5 cup vegetable oil = 14 lbs cannabis + 26.5 L vegetable oil / hr
- Wholesale $1400 / lb
    - $20,000 / hr for cannabis
- $0.06 / fl oz vegetable oil
    - $54 / hr for oil
- brownie mix + 2 eggs + 0.25 cup water = 16.3 brownies
- $0.10 / egg = $0.02 / brownie
- $2 / brownie mix box = $0.13 / brownie
    - $468 / hr for mix
    - $72 / hr for eggs

    ~$20,000 / hr total

$20 / brownie = $72,000 / hr

In[409]:=
```
PieChart[{20000, 468, 72, 54},
 ChartLegends → {"Cannabis", "Brownie Mix", "Eggs", "Vegetable Oil"}]
```

Out[409]=



Cannabis Curve

In[407]:=
```
r := (1 + 0.9 Cos[8 θ]) (1 + 0.1 Cos[24 θ]) (0.9 + 0.1 Cos[200 θ]) (1 + Sin[θ]);
Animate[
 PolarPlot[r, {θ, 0, 2 π},
  Axes → False,
  ColorFunction → Function[{x, y, t, r}, Hue[r + color]],
  ColorFunctionScaling → False,
  MaxRecursion → 5,
  PlotRange → All],
 {color, 0, 4},
 AnimationRunning → False]
```

Out[408]=