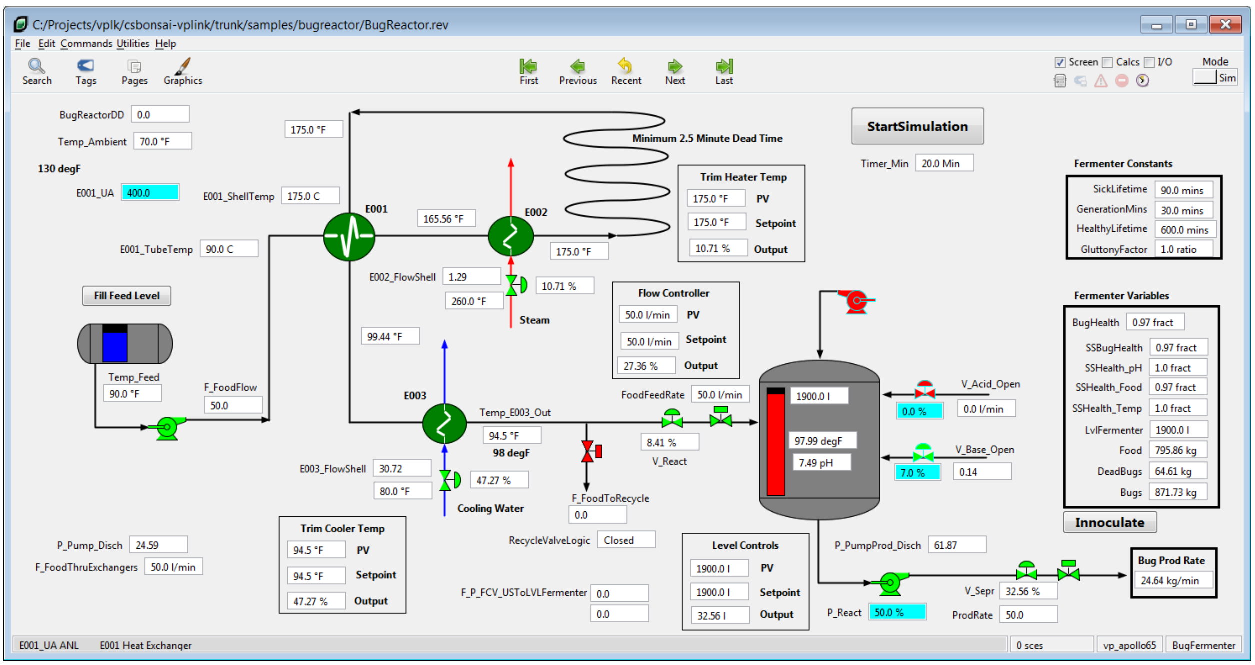
BUG REACTOR SIMULATION

Using VP Link to simulate a continuous fermenter



Abstract

There are a number of interesting control problems with this process.

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A continuous fermenter simulation has been built with VP Link. Below is a description of the elements of that simulation.

The process is shown below. The goal of the continuous fermenter is to avoid the time consuming operations of the batch reactor including deinventory, charging, and sterilization. In the continuous fermenter food for the bugs is sterilized continuously before being fed to the fermenter. This has a set of complications that arise due to the dead time introduced by the sterilization loop. In addition, the optimum residence time for the fermenter is dependent on the growth rate of the bugs in the fermenter. If the feed rate to too fast and the residence time is too short, then the bugs can be flushed out of the reactor before they have time to multiply. If the residence time is too long, then the bugs will be starved for food and their growth rate will be lower than the optimum. Ideally, the steady state is such that the production rate out the bottom of the reactor is such that bugs are removed from the fermenter as fast as they are growing. The trick is, knowing how fast they are growing is hard to measure.

This process generally starts with a fermenter that has been filled with sterilized media including some concentration of food. Bugs are introduced into the reactor, start to eat the food and multiply. The quantity of bugs in the reactor grows at an exponential rate, as the rate at which new bugs appear is proportional to the number of bugs in the reactor. Actually, the growth rate is dependent on how “happy” the bugs are in their environment. Bugs grow at the maximum rate at a certain temperature and pH (and if we want to make it more complicated, dissolved oxygen level), as long as there is sufficient food. An excess of food does not make the bugs grow even faster, as there is some limit as to their metabolism. But a scarcity of food does reduce the growth rate and causes some bugs to die, meaning they will never reproduce again, even if the food supply is restored.

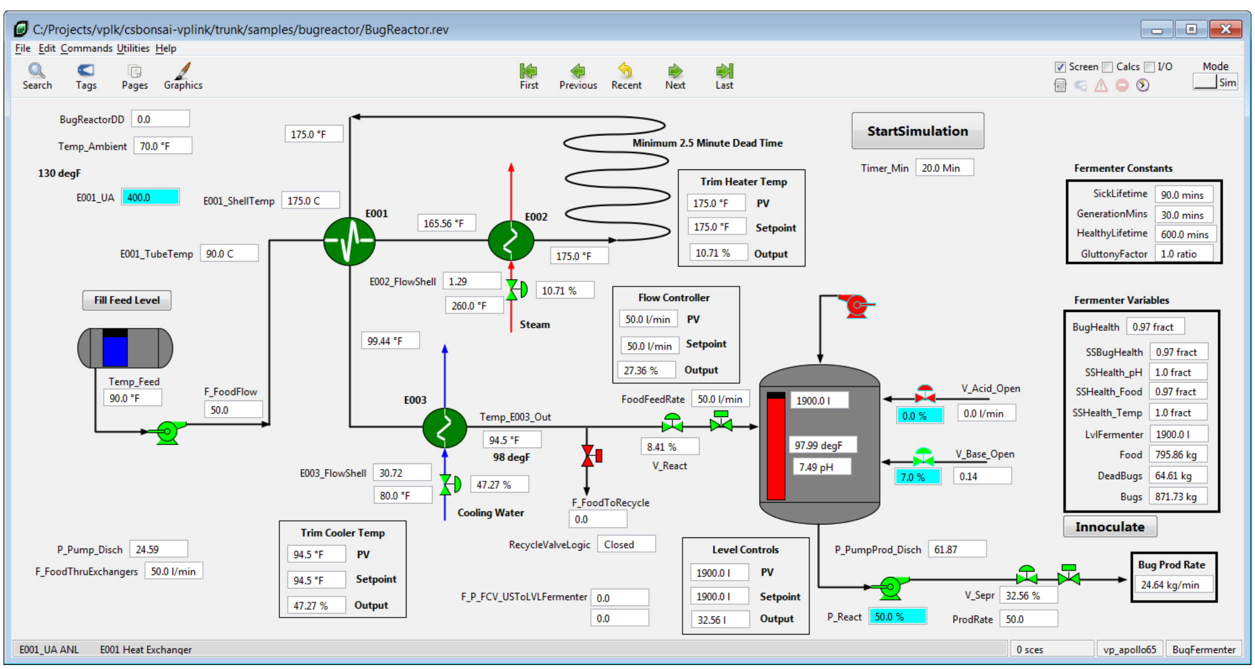

Figure 1 -- Process overview of the continuous fermenter

The food to the reactor will be automatically diverted back to the feed tank if the flow rate to the reactor falls below 15 l/min. This prevents a low flow situation in the steam heater. By keeping some recycle flow through the pasteurization loop, it allows for an easier start up. Also, the recycle valve will automatically close when the flow to the reactor is above 25 l/min, as the pump does not need waste capacity flowing back to the food tank at rates above that threshold. There are some flow disturbances associated with the recycle valve opening and closing, but the flow controller will restore the flow to the desired setpoint.

Here is what we know about the conditions in the bug reactor.

- Bugs grow exponentially in time when they are happy and have enough to eat.
- Bugs die. These bugs are still in the reactor (and will produce enzymes when they are sent downstream to be lysed). Dead bugs will never reproduce. Bugs can die because they are too old, or because conditions are not good, and they are no longer healthy. The farther the conditions are from optimum the fewer bugs remain healthy. Sick bugs die at a faster rate than healthy bugs.
- Bugs that are not healthy do not reproduce, but they could later if they get healthy again.
- Bugs like to be at 98 deg F.
- Bugs produce heat when they grow, so the fermenter must be cooled to maintain a steady temperature. The temperature controls do a pretty good job of controlling the fermenter temperature.
- Bugs like an environment where the pH is 7.5
- The food introduced to the reactor has a pH of 7.
- The waste product of growing bugs is basic, and as the bug growth rate increases, acid is required to maintain the pH at the proper level. You will see that there is no pH controller, but there are an acid and a base valve.

Your job, Mr. Phelps, should you choose to accept it, is to feed the reactor at the optimum rate to maximize the bug yield. Bug yield is the totalized value of the production rate times the concentration of bugs in the effluent stream. As always, the author will disavow any knowledge of a relation to a real process.

You may also want to investigate how you can start up the sterilization loop as fast as possible, getting the food to the desired temperature for the appropriate length of time. You can get the sterilization loop up to temperature by stopping the flow to the reactor. This will open the recycle valve and you can get the loop up to temperature while recycling food. Once you are ready to feed the reactor, increase the flow setpoint and allow the food to enter the reactor.

Other parts of the process that are important to know about.

The food needs to be pasteurized at 170 degrees F for at least three minutes, or 175 degrees for 2.5 minutes. If the pasteurization criteria are not met, then invasive bugs from the outside world will be introduced into the fermenter and wipe out the laboratory bugs which are unprepared to compete with bugs that have adapted to live in the competitive life environment we call planet Earth. This means that all the laboratory bugs die, and the only option is to drain the fermenter, re-sterilize it, and start the process back up again. This is very costly.

If it is noticed that the food has not been sterilized, it can be diverted to the drain to avoid introducing it to the fermenter. While this can save the bugs in the fermenter, the bugs will go without the food supply for as long as it takes to resolve the sterilization issue and get the food going back to the fermenter.

The most likely piece of equipment to fail is the steam exchanger, E002, that does the final heating of the food to the pasteurization temperature. If the food is heated above 190 deg F, then the food (think of thinned molasses), will start to caramelize on the surface of the steam exchanger, causing it to foul and lose its effectiveness[1].

Tags available in the Simulation:

[1] In the previous century, the author mis-operated this steam exchanger to the point that in order to transfer enough heat to the food through the fouled exchanger, the temperature controller increased the the steam temperature (and therefore pressure, as well) enough to blow the seals on the plate and frame exchanger. That was about a $30,000 mistake (in 1986 dollars)--plus lost production. Oops.

Tagname	Description	Mode	EULo	EUHi
Atm	External Pressure(0) lfngen:\otherusers\winston\BugReactor\Bu	Manual	0	100
BugHealth	EU=fract; What fraction of the live bugs are healthy	Auto	0	1
BugReactorDD	Liq Network Master, lfngen v14.3:\otherusers\winston\BugReac	Auto	0	100
Bugs	EU=kg; Amount of live bugs (healthy and unhealthy) in the reacto	Auto	0	5000
BugsProdRate	EU=kg/min; Production rate of bugs	Auto	0	1000
CWPID	Eu=%; Shellside inlet temperature	Auto	0	100
Centrifuge_P	Boundary Pressure(20) :\otherusers\winston\BugReactor\BugRe	Manual	0	80
DeadBugs	EU=kg How many dead bugs are there in the reactor	Auto	0	5000
E001	E001 Heat Exchanger	Auto	0	250
E001_FlowShell	Flow on shellside (Lb / hr)	Auto	0	1000000
E001_Flowtube	Flow on tubeside (Lb / hr)	Auto	0	1000000
E001_ShellTemp	Eu=C; Shellside inlet temperature	Auto	0	1200
E001_TubeTemp	Eu=C; Tubeside inlet temperature	Auto	0	1200
E001_UA	E001 Heat Exchanger	Manual	200	1000
E001_shell_Cp	Specific heat of shell side (BTU / LB F) (0.5)	Auto	0	100
E002	E002 Heat Exchanger	Auto	0	2000
E002_FlowShell	Flow on shellside (Lb / hr)	Auto	0	12
E002_Flowtube	Flow on tubeside (Lb / hr)	Auto	0	1000
E002_ShellTemp	Eu=Â°F; Shellside inlet temperature	Auto	0	1200
E002_TubeTemp	Eu=C; Tubeside inlet temperature	Auto	0	1200
E002_UA	Overall heat transfer coeff	Auto	0	10000000
E002_shell_Cp	Specific heat of shell side (BTU / LB F) (0.5)	Auto	0	100
E003	E003 Heat Exchanger	Auto	0	2000
E003_FlowShell	Flow on shellside (Lb / hr)	Auto	0	65
E003_Flowtube	Flow on tubeside (Lb / hr)	Auto	0	1000000
E003_ShellTemp	Eu=Â°F; Shellside inlet temperature	Auto	0	1200
E003_TubeTemp	Eu=C; Tubeside inlet temperature	Auto	0	1200
E003_UA	Overall heat transfer coeff	Auto	0	1000
E003_shell_Cp	Specific heat of shell side (BTU / LB F) (0.5)	Auto	0	100
F_BugsToCentrifuge	Flow(design=65) from P_PumpProd_Disch to Centrifuge_P lfnger	Auto	0	130
F_FoodFlow	Pump(design=65) from 1.2 to P_Pump_Disch netgen:\otherusers	Auto	0	98.9346
F_FoodThruExchangers	Flow(design=65) from P_Pump_Disch to P_Exch_Disch lfngen:\o	Auto	0	130
F_FoodToRecycle	Flow(design=65) from P_Exch_Disch to 1.2 lfngen:\otherusers\w	Auto	0	130
F_LVLFermenterToP_PumpProd_D	Pump(design=145.7) from 1.4 to P_PumpProd_Disch netgen:\Ot	Auto	0	221.766
F_P_FCV_USToLVLFermenter	Flow(design=145.7) from P_Pump_Disch to 1.4 lfngen:BugReact	Auto	0	291.4
F_P_PumpProd_DischToP_Reactor	Flow(design=145.7) from P_PumpProd_Disch to Centrifuge_P lfn	Auto	0	291.4
FlowPID	Eu=%; Shellside inlet temperature	Auto	0	100
FlowSetPoint	EU=l/min;	Auto	0	130
Food	EU=kg; The amount of food in the reactor	Auto	0	2000
FoodFeedRate	EU=l/min; Flow(design=65) from P_Exch_Disch to 1.4 lfngen:\ot	Auto	0	130
GenerationMins	EU=mins; How long does it take healthy bugs to double	Auto	0	600
GluttonyFactor	EU=ratio; How much food does a bug eat in a generation (vs. its	Auto	0	10
HealthyLifetime	EU=mins; How long do healthy bugs live?	Auto	0	1000
HeatIn	Eu=%; Shellside inlet temperature	Auto	0	100
HeatTerm	Takes inAccount Blower and Heat of Rxn in TempReactor	Auto	-500	500
LvlFermenter	Level Tag at press =1.4; lfngen:\otherusers\winston\BugReactor	Auto	0	2000
LvlFermenter_PID	EU=l; Setpoint for Level in the Fermenter (normally 300)	Auto	0	100
LvlFermenter_SP	EU=l; Setpoint for Level in the Fermenter (normally 300)	Auto	0	2000
LvlFoodTank	Level Tag at press =1.2; lfngen:\otherusers\winston\BugReactor	Manual	0	5000
PIDOutput	PID Output	Auto	0	100
P_Exch_Disch	Pressure(design=2) lfngen:\otherusers\winston\BugReactor\Bug	Auto	0	8
P_Food	Eu=%; Valve between 1.2 and P_Pump_Disch lfngen:LFN-Build-F	Auto	0	100
P_Food_Running		Auto	Stopped	Running
P_PumpProd_Disch	Pressure(design=50) lfngen:\otherusers\winston\BugReactor\Bu	Auto	0	200
P_Pump_Disch	Pressure(design=20) lfngen:\otherusers\winston\BugReactor\Bu	Auto	0	50
P_React	Eu=%; Reactor Discharge Pump Speed (normally 50%)	Manual	0	100
P_React_Running		Auto	Stopped	Running
P_Reactor	Boundary Pressure(1) :LFN-Build-Fermenter.xlsx[LFN]	Manual	0	5
ProdRate	Pump(design=65) from 1.4 to P_PumpProd_Disch netgen:\other	Auto	0	98.9346
Reactor_Temp	EU=degF; What is Temperature of the reactor	Auto	0	212
Reactor_pH	EU=pH; What is pH of the reactor	Auto	0	14
RecycleValveLogic		Auto	Closed	Open
SSBugHealth	EU=fract; The target bug health fraction	Auto	0	1
SSHealth_Food	EU=fract; Contribution of Food concentration to bug health (EU	Auto	0	1
SSHealth_Temp	EU=fract; Contribution of Temperature to bug health	Auto	0	1
SSHealth_pH	EU=fract; Contribution of pH to bug health	Auto	0	1
SickLifetime	EU=mins; How long do sick bugs live?	Auto	0	1000
TempCWSetPoint	Eu=Â°F;	Auto	0	200
TempSetPoint	Eu=Â°F;	Auto	0	200
Temp_Ambient	Eu=Â°F;	Auto	0	100
Temp_E001_ShellIn	Eu=Â°F;	Auto	0	300
Temp_E002_In	Eu=Â°F;	Auto	0	300
Temp_E002_Out	Eu=Â°F;	Auto	0	300
Temp_E003_In	Eu=Â°F;	Auto	0	300
Temp_E003_Out	Eu=Â°F;	Auto	0	300
Temp_Feed	Eu=Â°F;	Auto	0	100
Timer		Auto	0	10000
Timer_Min	Eu=Min	Auto	0	20
V_Acid_Open	EU=l/min; Rate of Acid addition	Auto	0	2
V_Acid_Open_Vlv	Eu=%;	Manual	0	100
V_Base_Open		Auto	0	2
V_Base_Open_Vlv	Eu=%;	Manual	0	100
V_Blower_Open		Manual	0	1
V_Cool	Eu=%; Valve between P_WatCool_US and P_FCV_US lfngen:LFN	Auto	0	100
V_Cool_Open		Auto	0	1
V_Hex	Eu=%; Valve between P_Pump_Disch and P_WatCool_US lfngen	Auto	0	100
V_Hex_Open		Auto	0	1
V_React	Eu=%; Valve between P_FCV_US and 1.4 lfngen:LFN-Build-Ferme	Auto	0	100
V_React_Open		Auto	Closed	Open
V_Recycle_Open		Auto	Closed	Open
V_Sepr	Eu=%; Valve between P_PumpProd_Disch and P_Reactor lfngen:	Auto	0	100
V_Sepr_Open		Auto	Closed	Open
V_Water	Eu=%;	Auto	0	100
WaterFeedRate	Flow(design=120) from 15 to 1.4 lfngen:\otherusers\winston\Bu	Auto	0	240
XV050	Some digital point	Auto	Off	On

Model Description

Pasteurization Loop

The pasteurization loop keeps the incoming food above 170 deg (setpoint of 175) for at least 2.5 minutes. The loop holds 180 liters of material.

Reactor

Brain Training

Pasteurization Loop

Use the PasteurizationStartup.icf file to initialize the model to a cold pasteurization loop. Train the brain to get the loop hot (175 degF) as fast as possible without going over 180 deg. The brain will manipulate the TempSetPoint tag to do this. You must maintain the outlet temperature of the pasteurization loop (i.e. all the values of Temp_E001_ShellIn[0..3]) between 174 and 180 for 3 minutes.

Reactor

Use the ReactorStartup.icf file to manipulate the inlet food rate, the level in the reactor and the inlet temperature of the food to maximize the bug production rate. Note that the "BugProdRate" actually indicates the kg/min of bugs that are leaving the reactor. All bugs count toward the yield of the process, even the dead ones. If you do not want to worry about the pH, use the Magic_pH_Control.icf in your SimConfig. If you do want to control the pH, use the acid and base valves. Note that you probably will not need to open either of them past 10%.

Still To Do

Still to do:

- Adjust the pH by pooping bugs.
- Add the section to this document that describes the model. Less for the brain design guy, but more for the eventual customer that is interested in how VP Link works to create their own models.
- Add controls for the automatic diversion of incompletely pasteurized food.
- Add description of the temperature vs. time dependence of the sterilization loop.