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Dependability Estimate for Sugar Plant with Standby Redundant Boiler

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ABSTRACT:
In this chapter, the author has considered a sugar plant for its reliability forecast by employing Supplementary variables technique. The whole system consists of seven subsystems connected in series. These subsystems are chain conveyor, cane cutter, crushing unit, filter, boiler, sulphonation process unit and crystallizer. Initially, the chain conveyor takes the sugar cane and sends these to cane cutter, where these are cut into fine small pieces. These small pieces of cane go to juicer from which we obtain the juice with some impurities. After filtration this impure juice goes to boiler where we boil this juice upto some standard temperature to remove all the impurities. Further this juice goes to sulphonation process unit to make its colour white. At last, pure juice goes to criystallizer and from this, we get white crystalline sugar, which can be packed. To improve system's overall performance, in this paper, the author has been taken one parallel redundant cutter, filter and boiler.

KEY WORDS : Sulphonation process, filter and boiler

INTRODUCTION:

In this chapter, the author has considered a sugar plant for its reliability by applying supplementary variables technique. The whole system consists of seven subsystems connected in series. These are: Cane conveying & Cane preparation , Milling(juice extraction), Sulphitation (Addition of lime and sulphur di oxide), Clarification (subsidation), Filtration & Evaporation. Initially, the conveyor carries the sugar cane then it is prepared. The prepared cane is sent to mills for juice extraction and extracted juice is screened through stationary and rotary screen. The juice extracted from mills having various impurities, is clarified by sulphitation process, allowed to settle (in clarifier) and filtered through rotary vacuum filters.

Clear juice is separated and concentrated into syrup during evaporation and further into massecuite from syrup in vacuum pans. Massecuite is centrifuged for separation of sugar and molasses .The obtained sugar is graded and packed.

AIMS OF SUGAR CRYSTALLIZATION:

Separation of sucrose from it's associated impurities by forming grains from liquid phase to solid phase. Our aim is to separate granular crystallizing particle by centrifugation and get maximum sugar recovery by maximum desugarisation of mother liquor. Crystallization is the process of further concentration of Sulphited syrup so as to form sugar crystals embedded in surrounded mother liquor called Massecuite. Next to natural solar evaporation, the batch pan is one of the oldest methods of concentration.

CRYSTAL GROWTH MECHANISM:

The sugar crystals growth in super saturated sugar solution takes place as a result of following two processes:

Transfer of sucrose molecules from the bulk of solution to the surface of crystal and incorporation of these molecules in the crystal lattice. The crystal growth depends on these two mechanisms and the slower process determines rate of crystallization. In the case of sucrose crystal suspended in a supersaturated sugar solution, sucrose molecule from the bulk of solution will be transported to the crystal face by diffusion, as the film near the crystal will be thin. As the sucrose molecules get deposited in crystal lattice, the film near the crystal has a lower degree of super saturation than the bulk of solution due to reduction in concentration of solute as also due to the effect of heat of crystallization. Crystallization is done in specially designed vessels called 'vacuum pans' (batch and continuous), following definite pan boiling scheme for production of four types of massecuites i.e. A, B, C_1 and C_2 in decreasing order of purities.

MASSECUITE BOILING SCHEMES:

The concentration of syrup coming from evaporator is continuing further in vacuum pan. The first massecuite obtained from virgin syrup is called A-massecuite and the mother liquor separated from A-massecuite in centrifugal is called A-molasses. However this A molasses still contains a high proportion of crystallisable sugar. It is therefore collected separately and used to build second strike. This operation may be repeated by several times, but number boiling soon becomes limited due to, Molasses becomes more and more exhausted i.e. purity of molasses lowers. All the sugar from molasses is not crystallisable since non-sugar immobilizes a certain proportion of sugar. The exhausted and low purity molasses becomes rich in non-sugar and viscosity increase beyond processing limit. The high viscosity creates circulation problems. For this purpose the number of boiling should be kept minimum. The number of boiling mainly depends upon syrup purity.

FORMULATION OF MATHEMATICAL MODEL:

By using probability consideration and limiting procedure, we obtain the following set of difference-differential equations, which is continuous in time, discrete in space and governing the behaviour of considered system:

$$\left[\frac{d}{dt}+\lambda_A+\lambda_B\alpha+\lambda_C\right]P_0(t)=\int_0^\infty P_A(x,t)\mu_A(x)dx+\int_0^\infty P_C(y,t)\mu_C(y)dy$$
$$+\int_0^\infty P_{SB}(z,t)\mu_B(z)dz \qquad \ldots(1)$$

$$\left[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_A(x)\right]P_A(x,t)=0 \qquad \ldots(2)$$

$$\left[\frac{\partial}{\partial y}+\frac{\partial}{\partial t}+\mu_C(y)\right]P_C(y,t)=0 \qquad \ldots(3)$$

$$\left[\frac{d}{dt}+(1-\alpha)+\lambda_A+\lambda_B+\lambda_C\right]P_S(t)=\lambda_B\alpha P_0(t)+\int_0^\infty P_{SA}(x,t)\mu_A(x)dx$$
$$+\int_0^\infty P_{SB}(z,t)\mu_B(z)dz+\int_0^\infty P_{SC}(y,t)\mu_C(y)dy \qquad \ldots(4)$$

$$\left[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_A(x)\right]P_{SA}(x,t)=0 \qquad \ldots(5)$$

$$\left[\frac{\partial}{\partial y}+\frac{\partial}{\partial t}+\mu_C(y)\right]P_{SC}(y,t)=0 \qquad \ldots(6)$$

$$\left[\frac{\partial}{\partial z}+\frac{\partial}{\partial t}+\mu_B(z)\right]P_{SB}(z,t)=0 \qquad \ldots(7)$$

$$\left[\frac{\partial}{\partial k}+\frac{\partial}{\partial t}+\mu_{SW}(k)\right]P_{SW}(k,t)=0 \qquad \ldots(8)$$

BOUNDARY CONDITIONS ARE:

$$P_A(0,t)=\lambda_A\ P_0(t) \quad \ldots(9)$$

$$P_C(0,t)=\lambda_C\ P_0(t) \quad \ldots(10)$$

$$P_{SA}(0,t)=\lambda_A\ P_S(t) \quad \ldots(11)$$

$$P_{SB}(0,t)=\lambda_B\ P_S(t) \quad \ldots(12)$$

$$P_{SC}(0,t)=\lambda_C\ P_S(t) \quad \ldots(13)$$

$$P_{SW}(0,t)=(1-\alpha)\ P_S(t) \quad \ldots(14)$$

INITIAL CONDITIONS ARE:

$P_0(0)=1$, otherwise all state probabilities are zero at $t=0$ ...(15)

SOLUTION OF THE MODEL:

In order to solve above mathematical model, we have to compute transition-state probabilities of fig-1(b). We shall use Laplace transform to solve above mathematical model. Taking Laplace transforms of equations (1) through (14) by using initial conditions (15), we obtain:

$$[s+\lambda_A+\lambda_B\alpha+\lambda_C]\overline{P}_0(s)=1+\int_0^\infty \overline{P}_A(x,s)\mu_A(x)dx+\int_0^\infty \overline{P}_C(y,s)\mu_C(y)dy + \int_0^\infty \overline{P}_{SB}(z,s)\mu_B(z)dz \quad \ldots(16)$$

$$\left[\frac{\partial}{\partial x}+s+\mu_A(x)\right]\overline{P}_A(x,s)=0 \quad \ldots(17)$$

$$\left[\frac{\partial}{\partial y}+s+\mu_C(y)\right]\overline{P}_C(y,s)=0 \quad \ldots(18)$$

$$[s+(1-\alpha)+\lambda_A+\lambda_B+\lambda_C]\overline{P}_S(s)=\lambda_B\alpha\overline{P}_0(s)+\int_0^\infty \overline{P}_{SA}(x,s)\mu_A(x)dx + \int_0^\infty \overline{P}_{SB}(z,s)\mu_B(z)dz+\int_0^\infty \overline{P}_{SC}(y,s)\mu_C(y)dy \quad \ldots(19)$$

$$\left[\frac{\partial}{\partial x}+s+\mu_A(x)\right]\overline{P}_{SA}(x,s)=0 \quad \ldots(20)$$

$$\left[\frac{\partial}{\partial y}+s+\mu_C(y)\right]\overline{P}_{SC}(y,s)=0 \quad \ldots(21)$$

$$\left[\frac{\partial}{\partial z}+s+\mu_B(z)\right]\overline{P}_{SB}(z,s)=0 \quad \ldots(22)$$

$$\left[\frac{\partial}{\partial k}+s+\mu_{SW}(k)\right]\overline{P}_{SW}(k,s)=0 \quad \ldots(23)$$

$$\overline{P}_A(0,s)=\lambda_A\ \overline{P}_0(s) \quad \ldots(24)$$

$$\overline{P}_C(0,s)=\lambda_C\ \overline{P}_0(s) \quad \ldots(25)$$

$$\overline{P}_{SA}(0,s)=\lambda_A\ \overline{P}_S(s) \quad \ldots(26)$$

$$\overline{P}_{SB}(0,s)=\lambda_B\ \overline{P}_S(s) \quad \ldots(27)$$

$$\overline{P}_{SC}(0,s)=\lambda_C\ \overline{P}_S(s) \quad \ldots(28)$$

$$\overline{P}_{SW}(0,s)=(1-\alpha)\ \overline{P}_S(s) \quad \ldots(29)$$

Integrating equation (17) subjected to boundary condition (24), we obtain

$$\overline{P}_A(x,s)=\lambda_A\overline{P_0}(s)\quad\exp\left\{-sx-\int\mu_A(x)dx\right\}$$

integrating this again w.r.t. 'x' from 0 to ∞, we get

$$\overline{P}_A(s)=\lambda_A\overline{P_0}(s)\quad\frac{1-\overline{S}_A(s)}{s}$$

or, $\overline{P}_A(s)=\lambda_A\overline{P_0}(s)D_A(s)$ ...(30)

Similarly, integrating equation (18) with the help of (25), we have

$$\overline{P}_C(y,s)=\lambda_C\overline{P}_0(s)\quad\exp\left\{-sy-\int\mu_C(y)dy\right\}$$

$$\Rightarrow\overline{P}_C(s)=\lambda_C\overline{P_0}(s)\,D_C(s)\qquad\text{...(31)}$$

Again, integrating (20) subjected to (26), we get

$$\overline{P}_{SA}(x,s)=\lambda_A\overline{P_S}(s)\quad\exp\left\{-sx-\int\mu_A(x)dx\right\}$$

$$\Rightarrow\overline{P}_{SA}(s)=\lambda_A\overline{P_S}(s)\,D_A(s)\qquad\text{...(32)}$$

Similarly, integrating (21),(22) and (23) with the help of boundary conditions (27), (28) and (29) respectively, we obtain

$$\overline{P}_{SC}(y,s)=\lambda_C\overline{P_S}(s)\quad\exp\left\{-sy-\int\mu_C(y)dy\right\}$$

$$\Rightarrow\overline{P}_{SC}(s)=\lambda_C\overline{P_S}(s)\,D_C(s)\qquad\text{...(33)}$$

$$\overline{P}_{SB}(z,s)=\lambda_B\overline{P_S}(s)\quad\exp\left\{-sz-\int\mu_B(z)dz\right\}$$

$$\Rightarrow\overline{P}_{SB}(s)=\lambda_B\overline{P_S}(s)\,D_B(s)\qquad\text{...(34)}$$

and $\overline{P}_{SW}(k,s)=(1-\alpha)\overline{P_S}(s)\quad\exp\left\{-sk-\int\mu_{SW}(k)dk\right\}$

$$\Rightarrow\overline{P}_{SW}(s)=(1-\alpha)\overline{P_S}(s)\,D_{SW}(s)\qquad\text{...(35)}$$

Again, solving equation (19) by the use of relevant expressions, we have

$$\left[s+(1-\alpha)+\lambda_A+\lambda_B+\lambda_C\right]\overline{P}_S(s)=\left[\lambda_A\overline{S}_A(s)+\lambda_C\overline{S}_C(s)+(1-\alpha)\overline{S}_{SW}(s)\right]\overline{P}_S(s)+\lambda_B\alpha\overline{P}_0(s)$$

$$\Rightarrow\overline{P}_S(s)=\frac{\lambda_B\alpha\overline{P}_0(s)}{s+(1-\alpha)+\lambda_A+\lambda_B+\lambda_C-\lambda_A\overline{S}_A(s)-\lambda_C\overline{S}_C(s)-(1-\alpha)\overline{S}_{SW}(s)}$$

$$=\frac{\lambda_B\alpha\overline{P}_0(s)}{\lambda_B+s\left[1+\lambda_A D_A(s)+\lambda_C D_C(s)+(1-\alpha)D_{SW}(s)\right]}$$

$$=A(s)\overline{P}_0(s)\qquad\text{(say)}\qquad\text{...(36)}$$

Finally, solving equation (16) by the use of related expressions, we get

$$\left[s+\lambda_A+\lambda_B\alpha+\lambda_C\right]\overline{P}_0(s)=1+\lambda_A\overline{S}_A(s)\overline{P}_0(s)+\lambda_C\overline{S}_C(s)\overline{P}_0(s)+\lambda_B A(s)\overline{P}_0(s)\overline{S}_B(s)$$

$$\therefore\ \overline{P}_0(s)=\frac{1}{B(s)}\qquad\text{(say)}$$

Thus, at last, we obtain the following Laplace transforms of various transition state probabilities of fig-1(b):

$$\overline{P}_0(s)=\frac{1}{B(s)}\qquad\text{...(37)}$$

$$\overline{P}_A(s)=\frac{\lambda_A D_A(s)}{B(s)}\qquad\text{...(38)}$$

$$\overline{P}_C(s)=\frac{\lambda_C D_C(s)}{B(s)}\qquad\text{...(39)}$$

$$\overline{P}_S(s) = \frac{A(s)}{B(s)} \quad \ldots(40)$$

$$\overline{P}_{SA}(s) = \frac{\lambda_A A(s) D_A(s)}{B(s)} \quad \ldots(41)$$

$$\overline{P}_{SB}(s) = \frac{\lambda_B A(s) D_B(s)}{B(s)} \quad \ldots(42)$$

$$\overline{P}_{SC}(s) = \frac{\lambda_C A(s) D_C(s)}{B(s)} \quad \ldots(43)$$

$$\overline{P}_{SW}(s) = \frac{(1-\alpha) A(s) D_{SW}(s)}{B(s)} \quad \ldots(44)$$

where, $A(s) = \dfrac{\lambda_B \alpha}{\lambda_B + s[1 + \lambda_A D_A(s) + \lambda_C D_C(s) + (1-\alpha) D_{SW}(s)]}$ ...(45)

and $B(s) = s + \lambda_A + \lambda_B \alpha + \lambda_C - \lambda_A \overline{S}_A(s) - \lambda_C \overline{S}_C(s) - \lambda_B A(s) \overline{S}_B(s)$ ...(46)

STEADY-STATE BEHAVIOUR OF CONSIDERED SYSTEM:

Using final value theorem of Laplace transform, viz., $\underset{t \to \infty}{Lim}\, P(t) = \underset{s \to 0}{Lim}\, s\, \overline{P}(s) = P$ (say), provided the limit on L.H.S exists, the following steady-state behaviour of considered system from equations (37) through (44):

$$P_0 = \frac{1}{B'(0)} \quad \ldots(47)$$

$$P_A = \frac{\lambda_A M_A}{B'(0)} \quad \ldots(48)$$

$$P_C = \frac{\lambda_C M_C}{B'(0)} \quad \ldots(49)$$

$$P_S = \frac{\alpha}{B'(0)} \quad \ldots(50)$$

$$P_{SA} = \frac{\lambda_A \alpha M_A}{B'(0)} \quad \ldots(51)$$

$$P_{SB} = \frac{\lambda_B \alpha M_B}{B'(0)} \quad \ldots(52)$$

$$P_{SC} = \frac{\lambda_C \alpha M_C}{B'(0)} \quad \ldots(53)$$

$$P_{SW} = \frac{(1-\alpha) \alpha M_{SW}}{B'(0)} \quad \ldots(54)$$

where, $B'(0) = \left[\dfrac{d}{ds} B(s)\right]_{s=0}$ and $M_K = -\overline{S}'_K(0) =$ Mean time to repair K^{th} unit.

NUMERICAL ILLUSTRATION:

For numerical illustration, let us consider the following values $\lambda_A = 0.002$, $\lambda_B = 0.006$, $\lambda_C = 0.003$, $\alpha = 0.6, C_1 = Rs7.00, C_2 = Rs2.00$ *and* $t = 0,1,2............$. Using these values in the equations (65) and (67), we compute the tables (1) and (2) respectively. Corresponding graphs have been shown in fig-1 & 2 respectively.

Table-1

t	Pup(t)
0	1
1	0.994377
2	0.98781
3	0.980644
4	0.973103
5	0.965338
6	0.957448
7	0.949499
8	0.941534
9	0.933581
10	0.92566

Table-2

t	G(t)
0	0
1	4.980996
2	9.919085
3	14.80895
4	19.64723
5	24.43187
6	29.16168
7	33.83602
8	38.45463
9	43.01753
10	47.52485

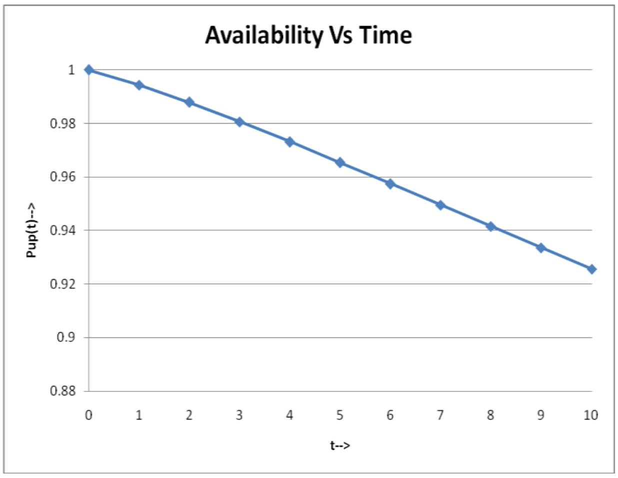

Fig-1

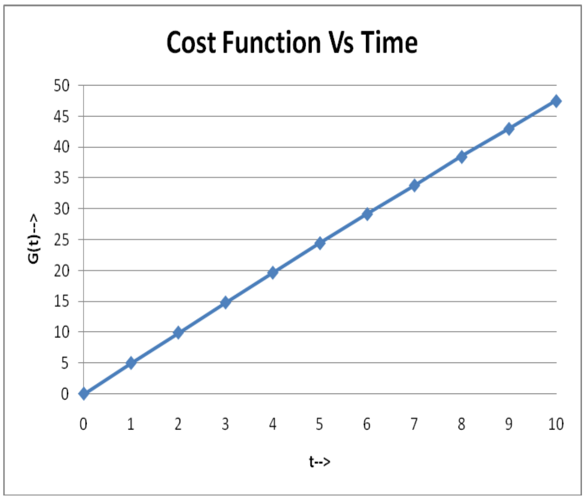

Fig-2

RESULTS AND DISCUSSION:

In this model, author has done reliability forecast for sugar plant. Possible state transition of considered system has been drawn and an equation obtained corresponding to each state by using “supplementary variables technique”. Laplace transform has been used to solve mathematical equations. Availability and cost function have been computed for considered system. A numerical example appended at last to highlight important results of this study.

Fig-1 shows the graph of “Availability Vs Time” and its values have given in table-1. Analysis of fig-2 yields that reliability of system decreases approximately in a constant manner. Fig-2 is the graph “Cost function Vs Time” and its values have given in table-2. Examination of fig-2 reveals that cost function of considered system increases as we make increases in the value of time t.

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