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Application of CAS Maxima to the reliability of Skimmed Milk Powder Production System of a Dairy Plant

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Abstract

The aim of the present paper is to deals with the reliability analysis of the serial processes in the skim milk powder production system of a dairy plant. This will be done by Runge Kutta method using CAS maxima.

Keywords*: Performance modeling, Chapman-Kolmogorov differential equations, Transient state reliability.*

1. Introduction

The skim milk powder systemhas six sub-systems, chiller, cream separator, pasteurizer,evaporator, drying chamber and packaging sub-system. These subsystemsare connected either in series or parallel with each other. Twosub-systems namely evaporator and drying chamber are supported by astandby sub-system with perfect switch over devices and by assumingthe non-failure of packaging sub-system, the remaining five subsystemsare subjected to failure. Arora and Kumar [3] discussed the availability analysis of steam and powder generation systems of thermal power plant. Dhillon and Singh [4] , Gupta et al.[8] developed the performance models and decision support system for a feed water unit of thermal power plant. Gupta and Tewari [7] presented the availability model for a thermal power plant. Khanduja et al. [9] presented the steady state behavior and maintenance planning of the bleaching system of paper plant. Kumar and Tewari [11] discussed the mathematical modeling and performance optimization of CO2 cooling system of a fertilizer plant using genetic algorithm.

Aggrawal Anil kr et all [1] has developed Schematic flow diagram of skim milk powder system with standby units and mathematicalformulation of the model by Chapman-Kolmogorov differentialequations by considering the exponentialdistribution of failure and repair rate of sub-systems, with the use of mnemonic rulefor these five sub-systems from the transition diagram. We use Runge-Kutta method to solve these differentialequations by using normalizing conditions to compute thereliability under transient state condition. Finally, to select best strategies for best the possible maintenance,each sub-system of the system has been analyzed.The findings of the paperwill be highly beneficial to the plant personnel to enhance the systemperformance by adopting the best possible maintenance strategies.

2. System Configuration and Assumptions

The skim milk powder system comprises of the following five sub-systems in series;

(1) ***Sub-system A (Chiller)***: In this sub-system the milk get filtered after testing and chilled to about5oC and storedin silos.

(2) ***Sub-system B (Cream separator)***: The fat from the milk get separated in theform of cream in this sub-system.

(3) ***Subsystem C (Pasteurizer)***: The process of Pasteurization is done in this sub-systemc.

(4) ***Subsystem D (Evaporator)***: It consists of two sub-systemsconnected in parallel; one operative and other in cold standby condition.

(5) ***Subsystem E (Drying chamber)***: It consists of two sub-systems connected inparallel; one operative and other in cold standby condition. Cream is converted in to powder form in this sub-system.

Notations:

- A, B,C,D,E: Indicates full working states of sub-systems.
- $\bar{D}$and$\bar{E}$:Indicates that the sub-system D and E are working under cold standby state.
- a,b,c,d,e : Indicates the failed states of sub-systems.
- Po(t):Probability of the system working with full capacity.
- P1 (t), P2 (t), P3(t): Probability of the system working under standby state.
- λi , i=1,2,3……7, represents, the constant failures rates of sub-systems A, B,C, D, $\bar{D}$, E, $\bar{E}$resp.
- μ_i, 1,2,3.....7 , represents, the constant repair rates of sub-systems A, B,C, D, $\bar{D}$, E, $\bar{E}$resp.
- Pj(t) , j=1,2,3,…..19represents the probability that the system is in jth state at time t.
- P' represents its derivative with respect to time (t).
- The symbols a,b,c,d and e represent the failed state of the sub-system A,B,C,D and E resp.

Assumptions:

- The states of all subsystems are mutually independent and the failure and repair rates are constant over time and follows exponential distribution.
- There are sufficient repair or replacement facilities available and there are no failures among the sub-systems.
- When one subsystem fails, it is instantaneously replaced by one of the standby subsystems (if any) and the switchover devices are perfect and the repairedsub-system behaves as new sub-system.

3. Mathematical Formulation of the System

The mathematical modeling of the system is carried out to determine the reliability of skimmed milk powder system and Chapman-Kolmogorov differentialequations are developed on the basis of Markov birth-death process as stated by Kumaret al.[10],[11]. The transition diagram obtained by Aggrawal Anil Kr.[1] depicts a simulation modelshowing all the possible states of skim milk powder system. Mathematical equations,(1) to (8) are developed by applying Markov-birth death process to each state one byone out of 19 states of transition diagram as explained by Garg et al. (2008and 2010).

$P'_o(t) = -X_oP_o(t) + \mu_1P_4(t) + \mu_2P_5(t) + \mu_3P_6(t) + \mu_4P_1(t) + \mu_6P_2(t)$ ………………………….... .(1)

$P'_1(t) = -X_1P_1(t) + \mu_1P_7(t) + \mu_2P_8(t) + \mu_3P_9(t) + \lambda_4P_o(t) + \mu_5P_{10}(t) + \mu_6P_3(t)$ ………………. (2)

$P'_2(t) = -X_2P_2(t) + \mu_1P_{11}(t) + \mu_2P_{12}(t) + \mu_3P_{13}(t) + \mu_4P_3(t) + \lambda_6P_0(t) + \mu_7P_{14}(t)$ ……………. (3)

$P'_3(t) = -X_3P_3(t) + \mu_1P_{15}(t) + \mu_2P_{16}(t) + \mu_3P_{17}(t) + \lambda_4P_2(t) + \mu_5P_{18}(t) + \lambda_6P_1(t) + \mu_7P_{19}(t)$…. (4)

Where

$X_o = (\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6)$

$X_1 = (\lambda_1+\lambda_2+\lambda_3+\mu_4+\lambda_5+\lambda_6)$

$X_2 = (\lambda_1+\lambda_2+\lambda_3+\lambda_4+\mu_6+\lambda_7)$

$X_3 = (\lambda_1+\lambda_2+\lambda_3+\mu_4+\lambda_5+\mu_6+\lambda_7)$

Similarly, we get

$P'_i(t) + \mu_j P_i(t) = \lambda_j P_o(t)$………… (5)

Where, i=4,5,6 ; j=1,2,3

$P'_i(t) + \mu_j P_i(t) = \lambda_j P_1(t)$………… (6)

Where, i=7,8,9,10 j=1,2,3,5

$P'_i(t) + \mu_j P_i(t) = \lambda_j P_2(t)$………… (7)

Where, i=11,12,13,14 ;j=1,2,3,7

$P'_i(t) + \mu_j P_i(t) = \lambda_j P_3(t)$………… (8)

Where, i=15,16,17,18,19 , j=1,2,3,5,7

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With initial conditions ;

$$P_j(0) = \begin{cases} 1 & i\; j = 1 \\ 0 & o\; he \end{cases} \ldots\ldots\ldots \quad (9)$$

The system of differential equations (1) to (8) with initial condition given by equation (9) are solved by Runga-Kutta method using CAS MAXIMA at different values of time (t).

The Reliability R(t) of the system can be computed by

$R(t) = P_o(t) + P_1(t) + P_2(t) + P_3(t)$……………… (10)

a) The failure and repair rates of evaporator ($\lambda 4$, $\mu 4$) and its standby unit ($\lambda 6$, $\mu 6$)are same.

b) The failure and repair rates of drying chamber ($\lambda 5$, $\mu 5$) and its standby unit ($\lambda 7$,$\mu 7$) are same.

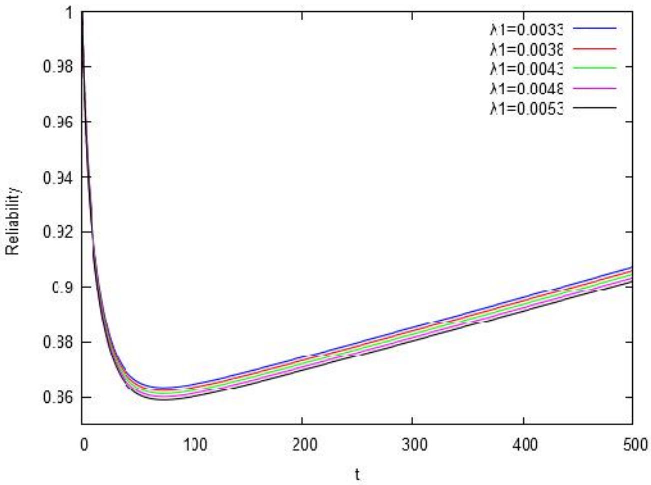
4. Performance Analysis

The reliability of the system is calculated by using equation (10) for variousvalues – combinations of failure and repair rates and presented in table 1-10;

o **Effect of failure and repair rates of Chiller on reliabilityof thesystem*:*** The reliability of the system is studied by varying theirvalues as; $\lambda1$=0.0033, 0.0038, 0.0043, 0.0048,0.0053 and$\lambda2$=0.0057;$\lambda3$=0.0073;$\lambda4$=0.0048;$\lambda5$=0.0451,$\mu1$=0.326, $\mu2$=0.073; $\mu3$=0.281;$\mu4$=0.092; $\mu5$=0.089.

Table 1.1: Effect of Failure and repair rate of Chiller on reliability of the system.

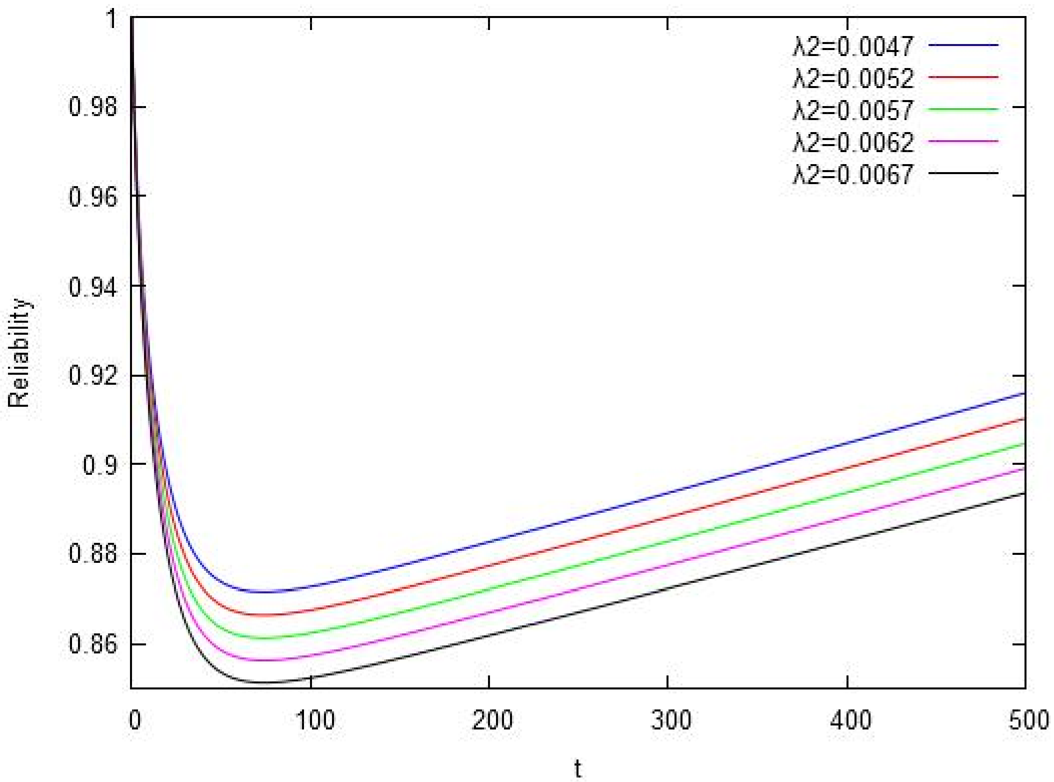
t \ λ_1	0.0033	0.0038	0.0043	0.0048	0.0053
30	0.87674037	0.87556628	0.87439534	0.87322756	0.87206291
60	0.86417921	0.86303895	0.86190169	0.86076743	0.85963616
90	0.86403935	0.86289615	0.86175596	0.86061878	0.85948461
120	0.8663167	0.86516587	0.86401809	0.86287335	0.86173165
150	0.86922588	0.86806669	0.86691059	0.86575757	0.86460761
180	0.87233518	0.8711675	0.87000295	0.8688415	0.86768314
210	0.8755181	0.87434188	0.87316882	0.87199889	0.8708321
240	0.8787339	0.87754911	0.8763675	0.87518907	0.8740138
270	0.88196891	0.8807755	0.87958531	0.87839833	0.87721455
300	0.88521843	0.88401635	0.88281754	0.88162197	0.88042963
330	0.88848083	0.88727005	0.88606257	0.88485836	0.88365741
360	0.89175559	0.89053606	0.88931985	0.88810695	0.88689736



o **Effect of failure rates of cream-separator on reliabilityof the system:** Thereliability of the system is studied by varyingtheir values as; λ_2=0.0047,0.0052, 0.0057, 0.0062, 0.0067 and λ_1=0.0038, λ_3=0.0073, λ_4=0.0048,λ_5=0.00451, μ_1=0.326, μ_2=0.073, μ_3=0.281,μ_4=0.092, μ_5=0.089.

Table 1.2: Effect of Failure rate of Cream separator on reliability of the system.

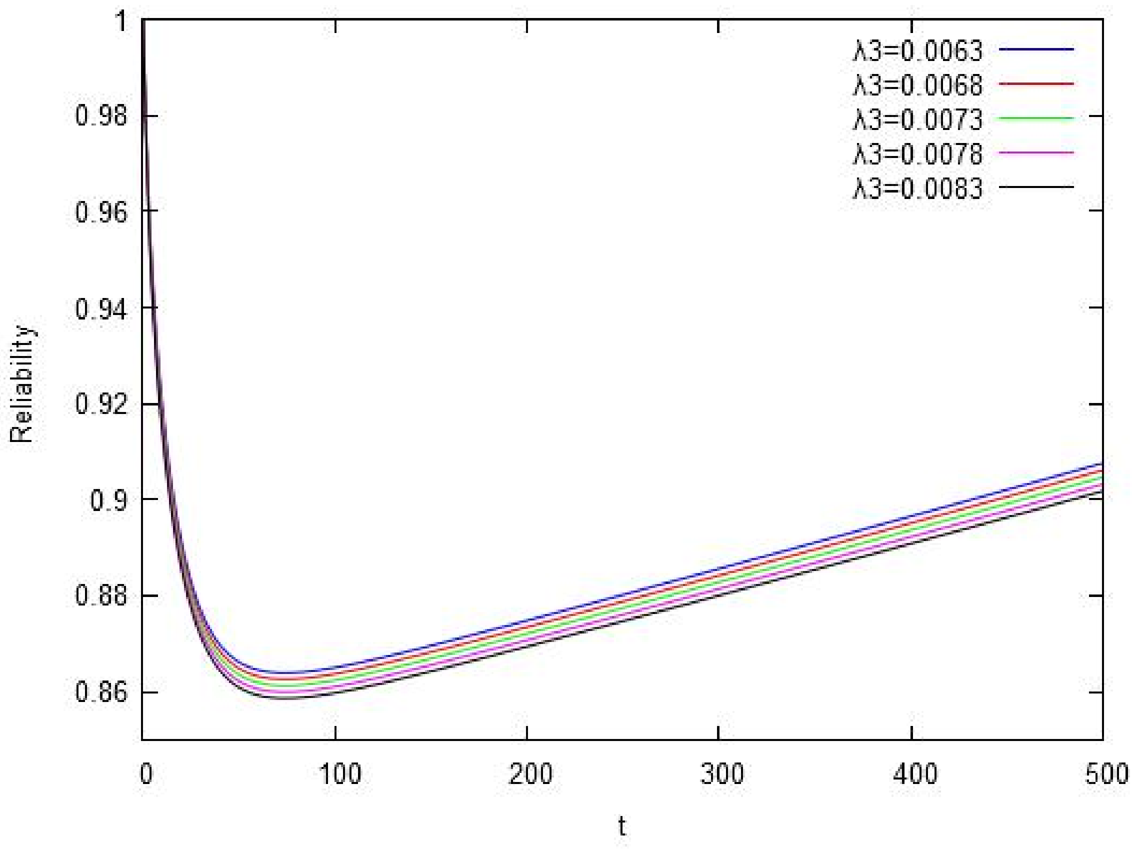
t \ λ_2	**0.0047**	**0.0052**	**0.0057**	**0.0062**	**0.0067**
30	0.88411423	0.87923214	0.87439534	0.86960332	0.86485555
60	0.87212929	0.86698607	0.86190169	0.85687519	0.85190564
90	0.87203033	0.86686281	0.86175596	0.85670873	0.85172009
120	0.874354	0.86915538	0.86401809	0.85894104	0.85392319
150	0.87731961	0.87208412	0.86691059	0.86179793	0.85674508
180	0.88048813	0.87521423	0.87000295	0.86485319	0.85976387
210	0.88373099	0.87841825	0.87316882	0.86798157	0.86285541
240	0.88700706	0.88165528	0.8763675	0.87114258	0.8659794
270	0.89030262	0.88491162	0.87958531	0.87432253	0.86912216
300	0.89361299	0.88818257	0.88281754	0.87751672	0.87227897
330	0.89693657	0.89146652	0.88606257	0.88072351	0.87544819
360	0.90027283	0.89476294	0.88931985	0.88394235	0.87862926



o **Effect of failure and repair rates of pasteurizer onreliability of the system:** Thereliability of the system is studied by varying their values as; λ_3=0.0063, 0.0068, 0.0073, 0.0078,0.0083 and λ_1=0.0043, λ_2=0.0057, λ_4=0.0048, λ_5=0.00451, μ_1=0.326,μ_2=0.073, μ_3= 0.281,μ_4=0.092, μ_5=0.089.

Table1.3: Effect of Failurerate of Pasteurizer on reliability of the system

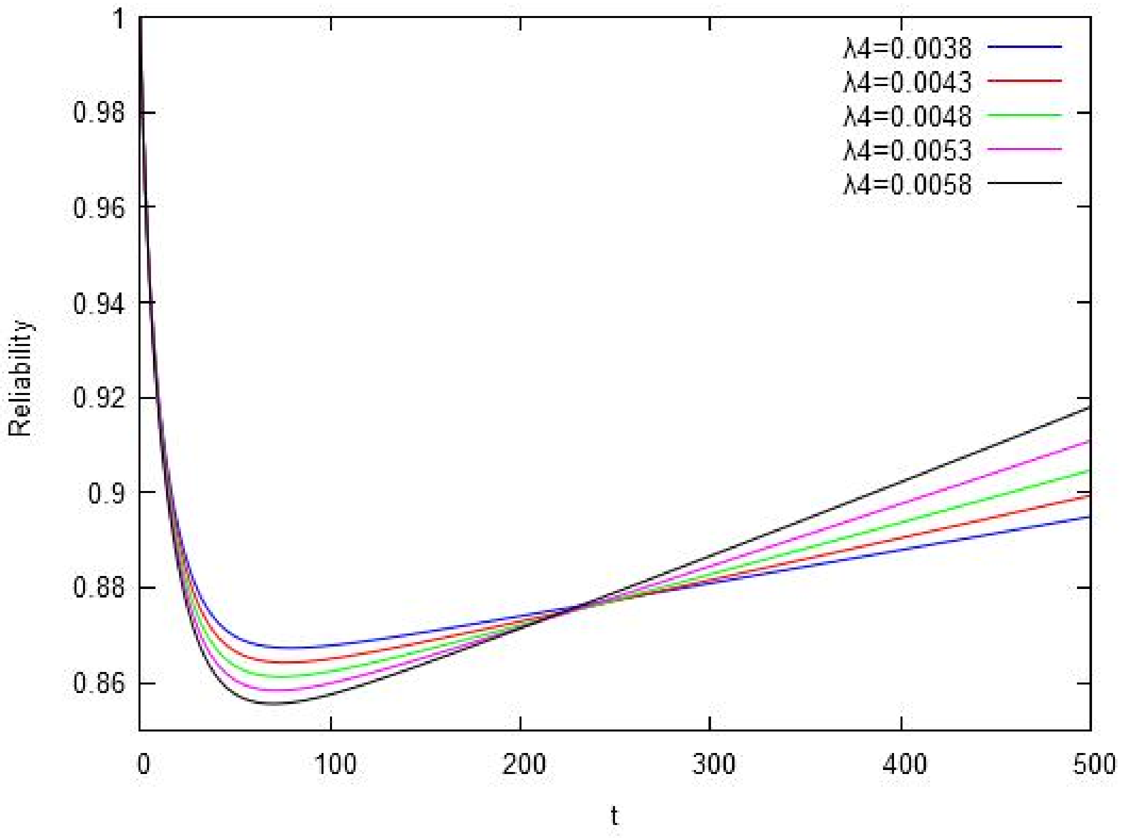
t \ λ_3	0.0063	0.0068	0.0073	0.0078	0.0083
30	0.8771216	0.87575633	0.87439534	0.87303861	0.87168612
60	0.86454537	0.86322151	0.86190169	0.86058591	0.85927415
90	0.86440592	0.8630789	0.86175596	0.86043707	0.85912221
120	0.86668563	0.8653498	0.86401809	0.86269047	0.86136692
150	0.86959748	0.86825196	0.86691059	0.86557336	0.86424025
180	0.87270951	0.87135413	0.87000295	0.86865595	0.86731311
210	0.87589516	0.87452987	0.87316882	0.87181199	0.87045938
240	0.87911372	0.87773847	0.8763675	0.87500081	0.87363837
270	0.8823515	0.88096623	0.87958531	0.87820871	0.8768364
300	0.88560379	0.88420847	0.88281754	0.88143097	0.88004874
330	0.88886899	0.88746356	0.88606257	0.88466598	0.88327378
360	0.89214656	0.89073096	0.88931985	0.88791319	0.88651097



o **Effect of failure and repair rates of evaporator on reliabilityof the system:** The reliabilityof the system is studied by varying theirvalues as; λ_4=0.0038,0.0043, 0.0048, 0.0053, 0.0058 andλ_1=0.0038,λ2=0.0057, λ3=0.0073, λ5=0.00451; μ1=0.326, μ2=0.073,μ3=0.281,μ4= 0.092 μ5=0.089.

Table 1.4: Effect of Failure and repair rate of evaporator on reliability of the system.

λ_4 / t	0.0038	0.0043	0.0048	0.0053	0.0058
30	0.87969679	0.87702714	0.87439534	0.87180083	0.86924305
60	0.86816124	0.86498443	0.86190169	0.85891065	0.85600901
90	0.86749184	0.86455142	0.86175596	0.85910083	0.85658157
120	0.86883184	0.86632754	0.86401809	0.86189644	0.85995583
150	0.870673	0.86866905	0.86691059	0.86538813	0.86409261
180	0.87266569	0.87118571	0.87000295	0.86910555	0.86848227
210	0.87471042	0.8737646	0.87316882	0.87290902	0.87297192
240	0.87677585	0.87636969	0.8763675	0.87675318	0.87751156
270	0.87885161	0.87898898	0.87958531	0.88062266	0.88208421
300	0.88093418	0.88161834	0.88281754	0.88451219	0.88668402
330	0.88302235	0.88425635	0.88606257	0.88841996	0.891309
360	0.88511571	0.88690254	0.88931985	0.89234536	0.89595852



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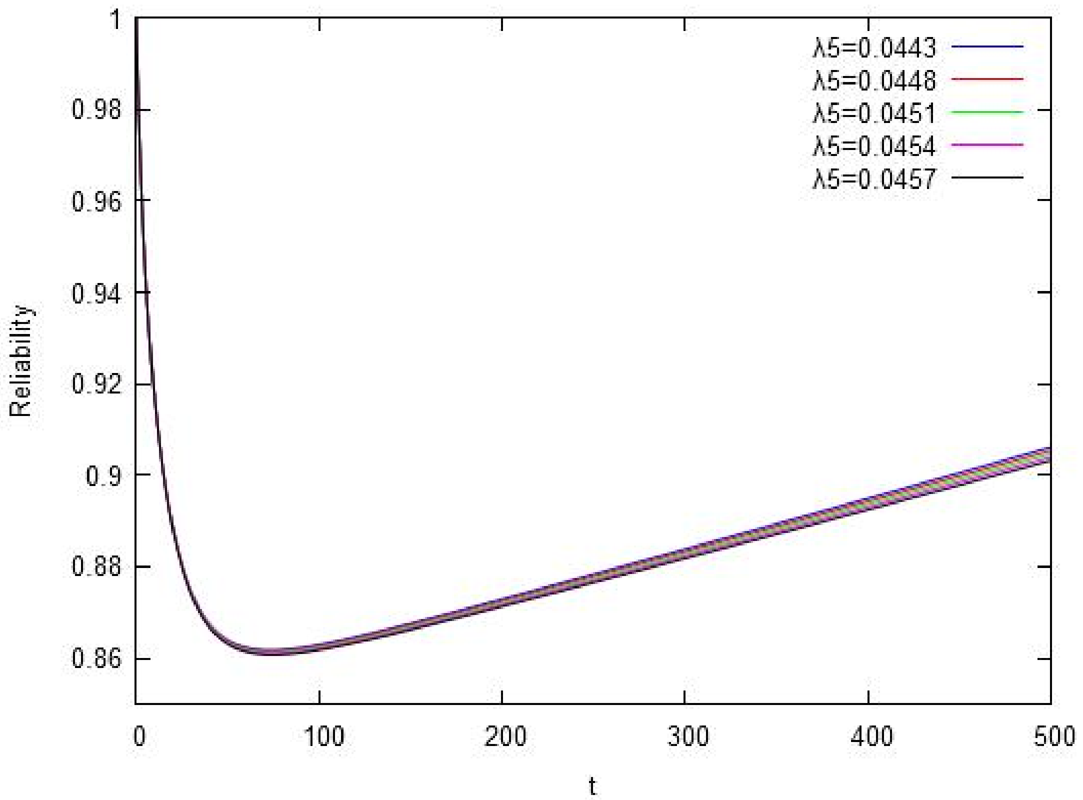
o **Effect of failure rates of drying chamber onreliabilityof the system:** The reliability of the system is studied by varyingtheir values as; λ5=0.00445, 0.00448, 0.00451,0.00454,0.00457 and. The failure and repair rates of other sub-systems have been takenas : λ1=0.0038, λ2=0.0057, λ3=0.0073, λ4=0.0048, µ1=0.326, µ2=0.073,µ3=0.281, µ4=0.092, µ5=0.089.

Table1. 5: Effect of Failure rate of drying chamber on reliability of the system.

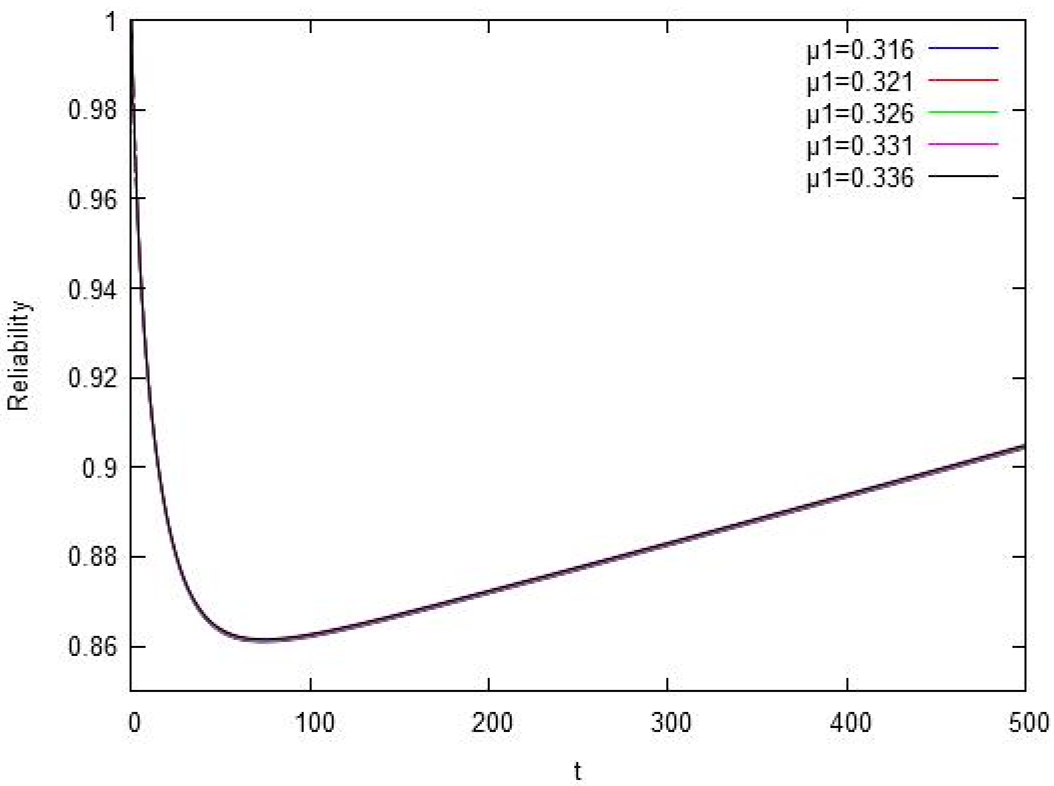
λ_5 / t	0.0445	0.0448	0.0451	0.0454	0.0457
30	0.87472029	0.87455766	0.87439534	0.87423334	0.87407165
60	0.86238077	0.86214102	0.86190169	0.86166279	0.86142431
90	0.86232446	0.86203995	0.86175596	0.86147249	0.86118955
120	0.86465672	0.86433707	0.86401809	0.86369976	0.86338209
150	0.86761384	0.86726181	0.86691059	0.86656019	0.8662106
180	0.87076948	0.87038572	0.87000295	0.86962116	0.86924034
210	0.87399856	0.87358311	0.87316882	0.87275568	0.8723437
240	0.87726076	0.87681346	0.8763675	0.87592288	0.8754796
270	0.88054249	0.88006313	0.87958531	0.87910901	0.87863422
300	0.88383909	0.88332745	0.88281754	0.88230933	0.88180282
330	0.88714894	0.8866048	0.88606257	0.88552223	0.88498378
360	0.89047152	0.88989463	0.88931985	0.88874716	0.88817654



o **Effect of repair rates of Chiller on reliability of the system:** The long run availability of the system is studied by varying their values as: μ1=0.316, μ1=0.321, μ1=0.326, μ1=0.331, μ1=0.336, whereas λ1:0.0043, λ2:0.0057, λ3:0.0073, λ4:0.048, λ5:0.0451 and , μ2=0.073, μ3=0.281, μ4=0.092, μ5=0.089 are kept fixed.

Table 2.1: Effect of repair rate of Chiller on reliability of the system.

t \ μ_1	0.316	0.321	0.326	0.331	0.336
30	0.87407384	0.87423709	0.87439534	0.87454882	0.87469773
60	0.86159249	0.86174948	0.86190169	0.86204936	0.86219267
90	0.86144635	0.86160354	0.86175596	0.86190383	0.86204735
120	0.86370648	0.86386468	0.86401809	0.86416692	0.86431137
150	0.86659673	0.86675607	0.86691059	0.8670605	0.86720599
180	0.86968679	0.8698473	0.87000295	0.87015395	0.87030051
210	0.87285035	0.87301203	0.87316882	0.87332092	0.87346855
240	0.87604672	0.87620958	0.8763675	0.87652071	0.87666942
270	0.8792622	0.87942624	0.87958531	0.87973963	0.87988942
300	0.88249209	0.88265732	0.88281754	0.88297298	0.88312385
330	0.88573476	0.88590118	0.88606257	0.88621913	0.88637109
360	0.88898968	0.8891573	0.88931985	0.88947754	0.8896306



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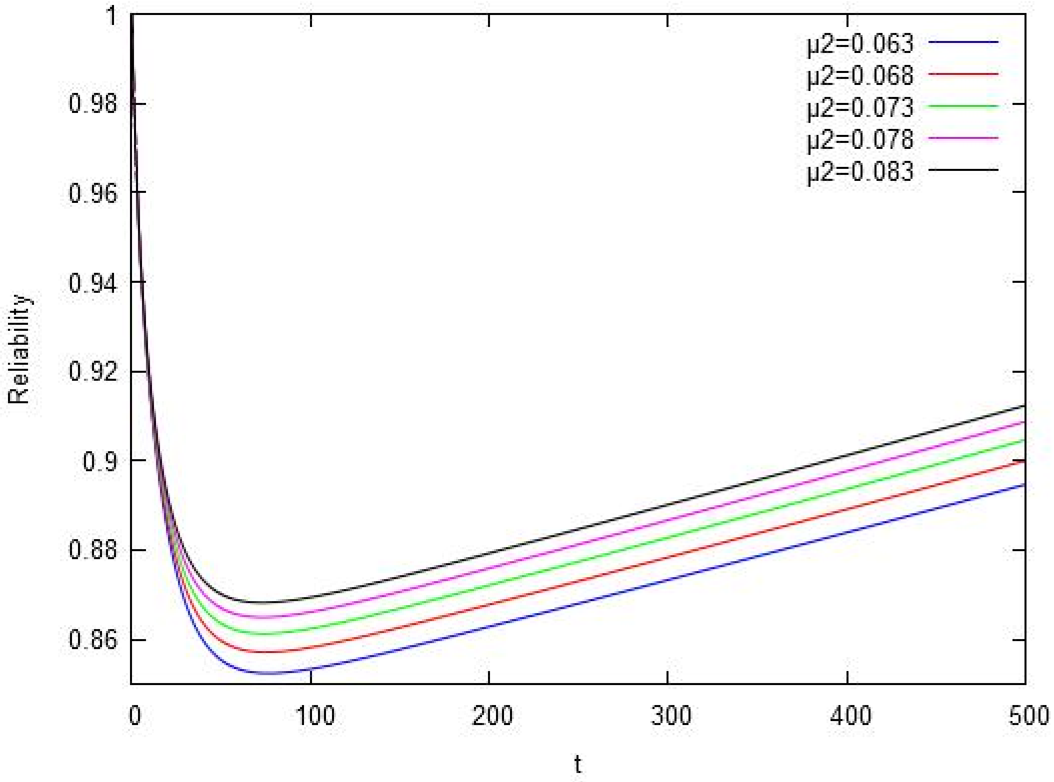
o **Effect of repair rate of cream-separator on reliability of the system:**The long run availability of the system is studied by varying their values as:μ2=0.063, μ2=0.068, μ2=0.073, μ2=0.078, μ2=0.083, whereas λ1:0.0043, λ2:0.0057 , λ3:0.0073, λ4:0.048, λ5:0.0451 and , μ1=0.326, μ3=0.281, μ4=0.092, μ5=0.089 are kept fixed.

Table 2.2: Effect of repair rate of cream-separatoron reliability of the system.

t \ μ2	**0.063**	**0.068**	**0.073**	**0.078**	**0.083**
30	0.86824638	0.87144511	0.87439534	0.87712038	0.87964109
60	0.85332324	0.85787048	0.86190169	0.86549328	0.8687085
90	0.8527501	0.85755212	0.86175596	0.86546391	0.86875703
120	0.85491134	0.85977333	0.86401809	0.86775539	0.87107074
150	0.85773707	0.86263565	0.86691059	0.87067375	0.87401178
180	0.86076335	0.86569725	0.87000295	0.87379324	0.87715546
210	0.86386221	0.86883181	0.87316882	0.8769868	0.88037368
240	0.8669934	0.87199896	0.8763675	0.88021338	0.8836251
270	0.87014336	0.87518507	0.87958531	0.88345921	0.8868959
300	0.87330741	0.87838544	0.88281754	0.88671961	0.89018138
330	0.87648392	0.88159845	0.88606257	0.88999295	0.89347994
360	0.87967233	0.88482354	0.88931985	0.8932787	0.89679103



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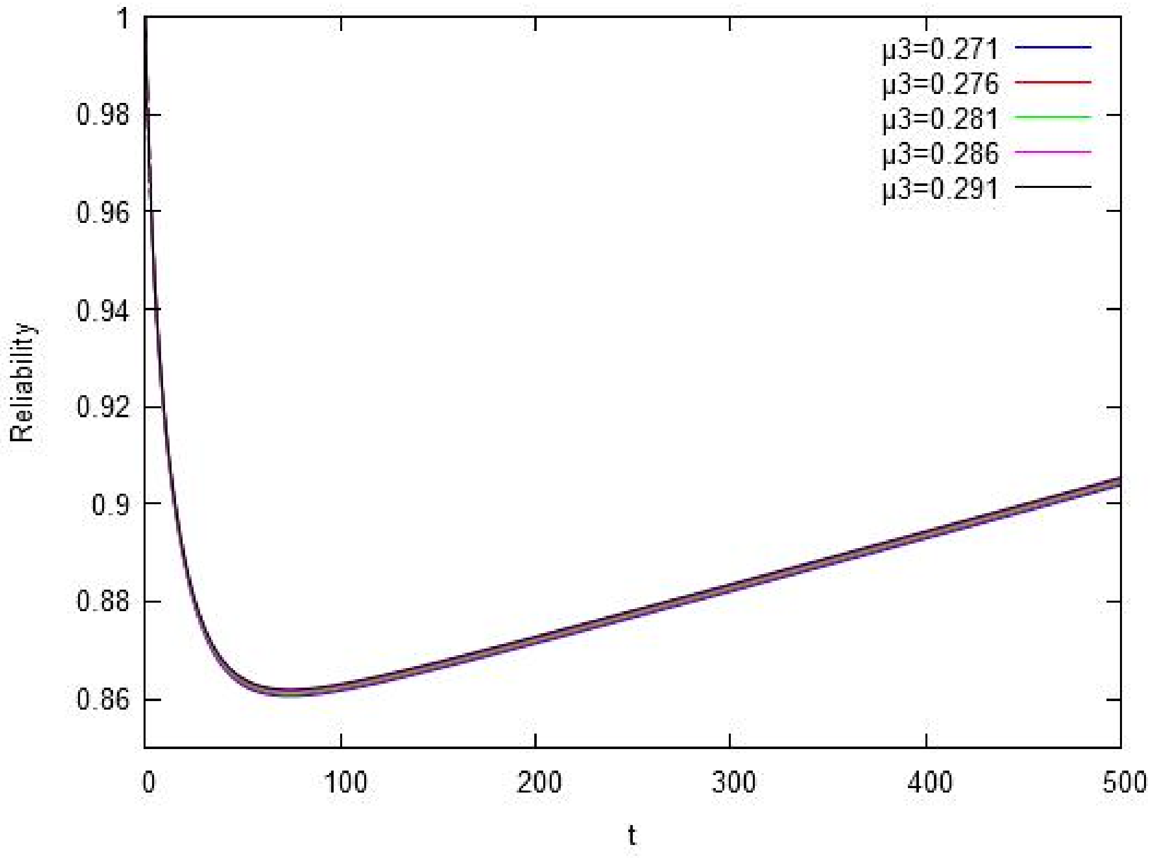
o **Effect of repair rates of pasteurizer on reliability of the system:** The long run availability of the system is studied by varying their values as: μ_3=0.271, μ_3=0.276, μ_3=0.281, μ_3=0.286, μ_3=0.291, whereas λ_1:0.0043, λ_2:0.0057 , λ_3:0.0073, λ_4:0.048, λ_5:0.0451 and , μ_1=0.326, μ_2=0.073, μ_4=0.092, μ_5=0.089 are kept fixed.

Table 2.3: Effect of repair rate of pasteurizeron reliability of the system.

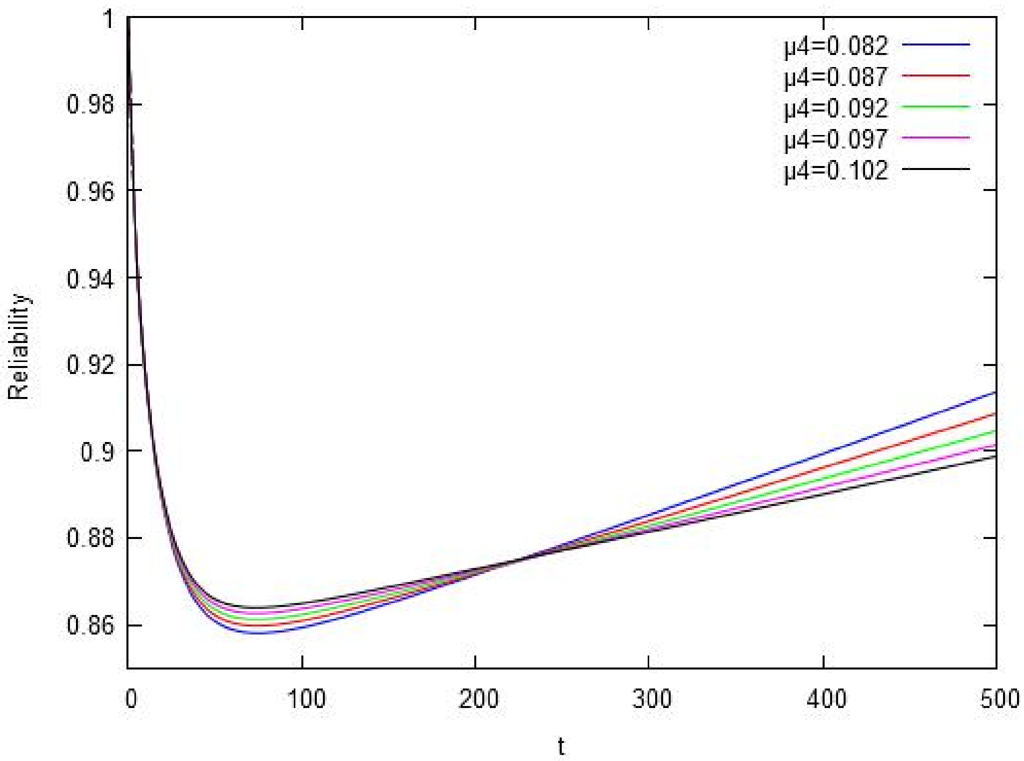
t \ μ3	**0.271**	**0.276**	**0.281**	**0.286**	**0.291**
30	0.87365504	0.8740318	0.87439534	0.87474635	0.87508545
60	0.86119164	0.86155296	0.86190169	0.86223848	0.86256393
90	0.86104537	0.86140695	0.86175596	0.86209304	0.8624188
120	0.86330295	0.86366684	0.86401809	0.86435733	0.86468518
150	0.8661903	0.86655681	0.86691059	0.86725228	0.8675825
180	0.86927739	0.86964658	0.87000295	0.87034714	0.87067977
210	0.87243796	0.87280985	0.87316882	0.87351552	0.87385058
240	0.87563133	0.87600592	0.8763675	0.87671673	0.87705423
270	0.87884379	0.87922111	0.87958531	0.87993708	0.88027703
300	0.88207065	0.8824507	0.88281754	0.88317185	0.88351427
330	0.88531028	0.88569307	0.88606257	0.88641944	0.88676434
360	0.88856213	0.88894769	0.88931985	0.8896793	0.89002669



o **Effect of repair rates of evaporator on reliability of the system:** The long run availability of the system is studied by varying their values as: $\mu4=0.271$, $\mu4=0.276$, $\mu4=0.281$, $\mu_4=0.286$, $\mu_4=0.291$, whereas $\lambda1:0.0043$, $\lambda2:0.0057$, $\lambda3:0.0073$, $\lambda4:0.048$, $\lambda5:0.0451$ and $\mu1=0.326$, $\mu2=0.073$, $\mu3=0.281$, $\mu4=0.092$, $\mu5=0.089$ are kept fixed.

Table 2.4: Effect of repair rate ofevaporator on reliability of the system.

t \ μ_4	0.082	0.087	0.092	0.097	0.102
30	0.87267125	0.87355611	0.87439534	0.87519196	0.87594874
60	0.85892443	0.86047065	0.86190169	0.86322894	0.86446244
90	0.85864923	0.86026979	0.86175596	0.86312309	0.86438441
120	0.86135035	0.86273869	0.86401809	0.86520064	0.86629679
150	0.86494529	0.86595533	0.86691059	0.86781371	0.86866756
180	0.86886109	0.86942398	0.87000295	0.87058675	0.87116757
210	0.87290763	0.87299008	0.87316882	0.87341591	0.87371091
240	0.87701615	0.8766009	0.8763675	0.87626954	0.87627277
270	0.88116078	0.88023771	0.87958531	0.87913753	0.87884562
300	0.88533158	0.8838937	0.88281754	0.88201659	0.88142714
330	0.88952473	0.88756642	0.88606257	0.88490565	0.88401659
360	0.89373877	0.89125498	0.88931985	0.88780436	0.88661376



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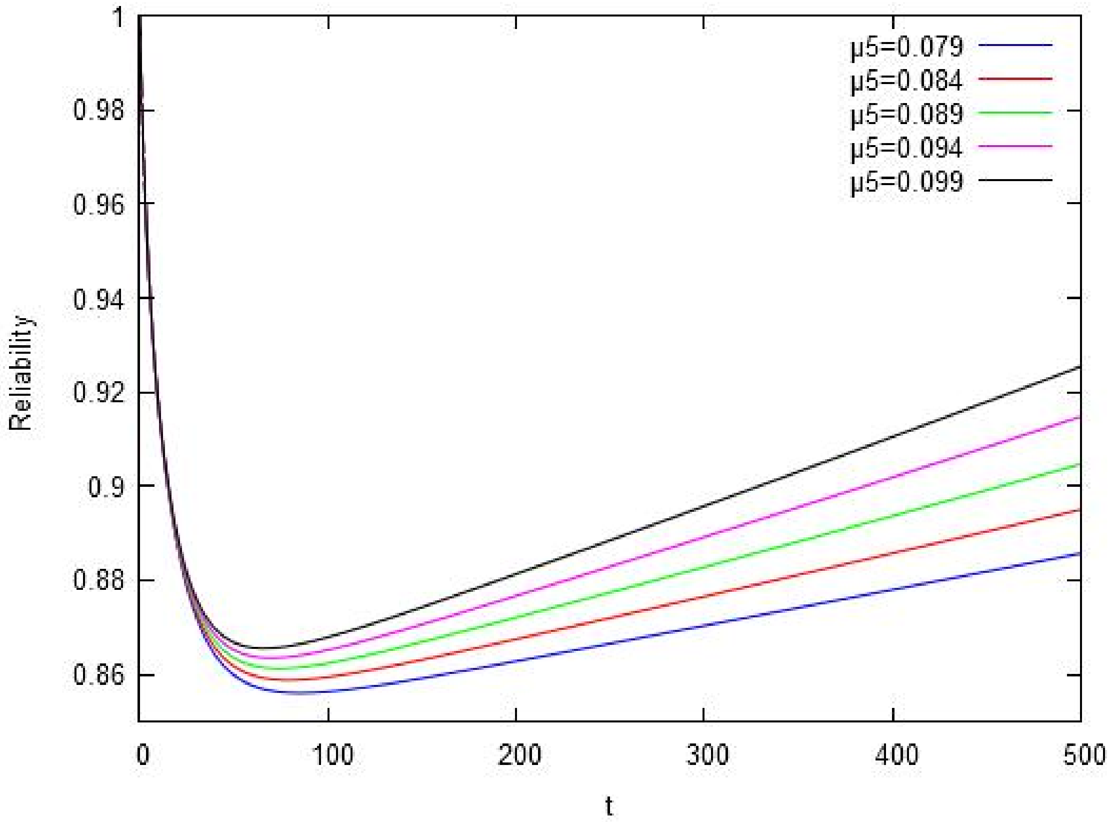
o **Effect of repair rates of drying chamber on reliability of the system:**The long run availability of the system is studied by varying their values as:μ5=0.079, μ5=0.084, μ5=0.089 μ5=0.094 μ5=0.099 whereas λ1:0.0043, λ2:0.0057 , λ3:0.0073, λ4:0.048, λ5:0.0451 andμ1=0.326, , μ2=0.073, μ3=0.281, μ4=0.092,are kept fixed.

Table 2.5: Effect of repair rate ofdrying chamberon reliability of the system.

t \ b5	0.079	0.084	0.089	0.094	0.099
30	0.87230934	0.87337784	0.87439534	0.87536593	0.87629335
60	0.85762742	0.85983124	0.86190169	0.8638572	0.865714
90	0.85608579	0.85900269	0.86175596	0.86437702	0.86689313
120	0.85726626	0.86072057	0.86401809	0.86719911	0.87029872
150	0.85918088	0.86311179	0.86691059	0.87062386	0.87429278
180	0.86132595	0.86571423	0.87000295	0.87424374	0.87848318
210	0.86355085	0.86839159	0.87316882	0.87793883	0.88275344
240	0.86580686	0.87110002	0.8763675	0.8816702	0.88706524
270	0.86807758	0.87382479	0.87958531	0.88542467	0.89140547
300	0.87035735	0.87656086	0.88281754	0.88919769	0.89576955
330	0.87264421	0.87930647	0.88606257	0.8929877	0.90015595
360	0.87493747	0.88206104	0.88931985	0.89679419	0.90456416



5. Discussion and Conclusion

The table 1.1 shows that increase in failure rate (λ1) of chiller decreases the system reliability but the table 2.1 shows that reliability increase as repairrate (μ1) of chiller increase. Similar pattern is observed for cream separator, pasteurizer,evaporator and drying chamberThe optimum reliability achieved is nearly 90% with best fitting of failure and repair rates of all subsystems of plants. Variation of availability becomes constant after long time. Such results might be useful for optimization performance of the skimmed milk powder system.

References

[1] Aggrawal,Anil Kr., Sanjeev Kumar., Vikram Singh., Performance Modelling and Availability Analysis of Skimmed Milk Powder Production System of a dairy Plant., IJAFST., Volume4., Number 9(2013)., pp., 851-858

[2] Adhikary, D. D., Bose, G. K., Chattopadhyay, S. D., Bose, D. and Mitrad ,S.(2012), RAM investigation of coal-fired thermal power plants: A case study",*International Journal of Industrial Engineering Computations*, **3**, pp.423-434.

[3] Arora, N. and Kumar, D. (1997), Availability analysis of steam and powergeneration systems in thermal power plant", *Microelectronic Reliability*, **37**,pp.795-799.

[4] B.S. Dhillon and C. Singh (1981), *Engineering reliability-new techniques andapplications*. New York: John Wiley and Sons.

[5] E. Balaguruswamy (1984), *Reliability Engineering*, Tata McGraw hill, NewDelhi.

[6] Gupta, P., Lal, A.K., Sharma, R.K. and Singh, J. (2005), Behavioral Study ofthe Cement manufacturing Plant – A Numerical Approach", *Journal ofMathematics and Systems Sciences*, **1**, pp.50-70.

[7] Gupta, S. and Tewari ,P.C. (2011), Simulation Modeling In a AvailabilityThermal Power Plant, *Journal of Engineering Science and TechnologyReview*, **4**, *2* ,pp. 110-117 .

[8] Gupta, S., Kumar, A., Sharma, R. and Tewari, P.C. (2008), A performancemodeling and decision support system for a feed water unit of a thermal powerplant, *S A J Ind. Engg*., **19**, *2* pp.125–34.

[9] Khanduja, R.,Tewari, P.C. and Kumar, D. (2012), Steady state behavior andmaintenance planning of bleaching system in a paper plant, *InternationalJournal of Industrial Engg.* , **7**, *12*, pp., 39-44.

[10] Kumar, S., Tewari, P.C. and Sharma, R. (2007), Simulated availability of CO2cooling system in a fertilizer plant, *Ind. Eng. J. (Indian Inst Ind Eng,Mumbai)*, **36**, *10*, pp.19–23.

[11] Kumar,S. and Tewari, P.C. (2011) , Mathematical modeling and performance optimization of CO2 cooling system of a fertilizer plant, *International Journalof Industrial Engineering Computations*, **2**, pp. 689–98.

[12] L.S. Srinath (1994), *Reliability Engineering*; 2nd edition, East-West Press Pvt.Ltd; New Delhi, India.