# 3. INDUSTRIAL COMPUTATIONAL MECHANICS

## 3.1 Numerical Simulation of ECTN Fluid Flow: Resolution of Flow Anomalies

In the experiments of sphere settling in viscoelastic fluids, several unusual phenomena have been observed such as, time dependent settling velocities of consecutively dropped identical spheres, large *restoration* time required for the successively dropped spheres to achieve the same terminal velocities and, unusual velocity transients of settling spheres. These and other unusual observations have remained unexplained so far despite nearly four decades of experimental work in this area. A mathematical formulation of the energetically crosslinked transient network (ECTN) model has been able to predict several flow anomalies such as double overshoots in shear start-up, sudden jump in steady shear viscosity and maximum in steady elongational viscosity seen in the rheological studies of polar polymer solutions. The ECTN model is employed here to study the viscoelastic flow past immersed bodies with the goal of finding probable solutions to the hitherto unresolved flow anomalies described above.

A single cylinder, a two-cylinder system and multiple cylinders translating in a channel have been considered. Computations show that ECTN model can lead to a longer stress wake (Fig. 3.1.1), which can affect the motion of other bodies in the wake, upto a considerable distance. Computations for two cylinders translating along the channel axis show that the second cylinder experiences a lower drag due to the wake effect of the first cylinder (Fig. 3.1.2). For a sequence of cylinders, the drag is found to reach an asymptotic value by about fourth or fifth cylinder.

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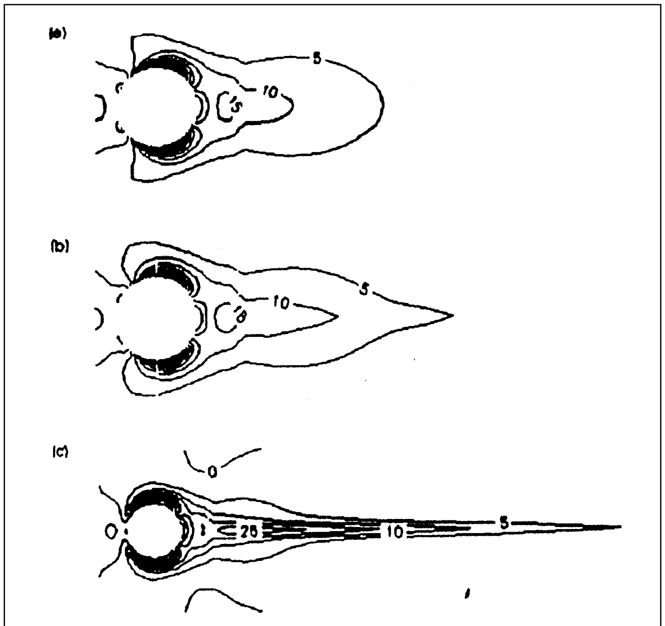
**Fig. 3.1.1.** Stress wake behind a single cylinder; (a) Oldroyd B (We =0.5), (b) ECTN ($We^e$ =2) and, (c) ECTN ($We^e$ =4)



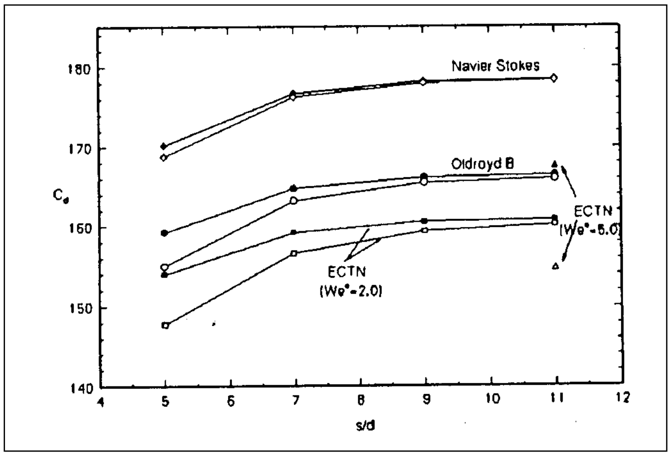




**Fig. 3.1.2.** Drag coefficient (Cd) for a two-cylinder system; full symbols for the first cylinder and hollow for the second cylinder.

## 3.2 Investigation of Negative Wake in Viscoelastic Fluid Flow

Flow in the wake of a settling body is generally towards the body. However, in experiments involving non-Newtonain fluids, it has been observed that the flow could be away from the body. This is referred to as n*egative wake* and has been investigated here. Settling of a cylinder of diameter *D* in a channel of width *W* is considered; Phan-Thien-Tanner model which exhibits both shear thinning and viscoelasticity is employed. Computations for Deborah number *De* = 5.95 show a negative wake for smaller values of *W/D* (Fig. 3.2.1). As the walls are moved away, the negative wake diminishes, and disappears for *W/D* > 10. Next, we consider a larger value of *W/D* = 20 and vary *De* from 5.95 to 11, and then 15. The negative wake which was absent in the solution for *De* = 5.95 is found in the solutions for *De* = 11 and 15 (Fig. 3.2.2). We can therefore conclude that negative wake occurs basically due to the wall confinement and viscoelasticity.

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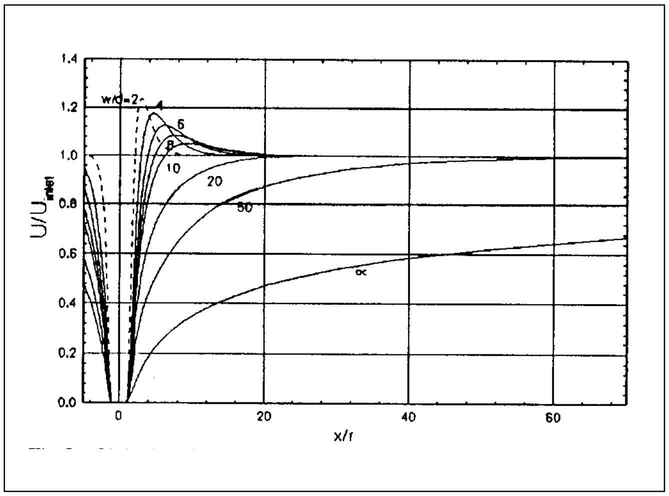



**Fig. 3.2.1.** Velocity along the wake for various *w/d* with *De*=5.95.

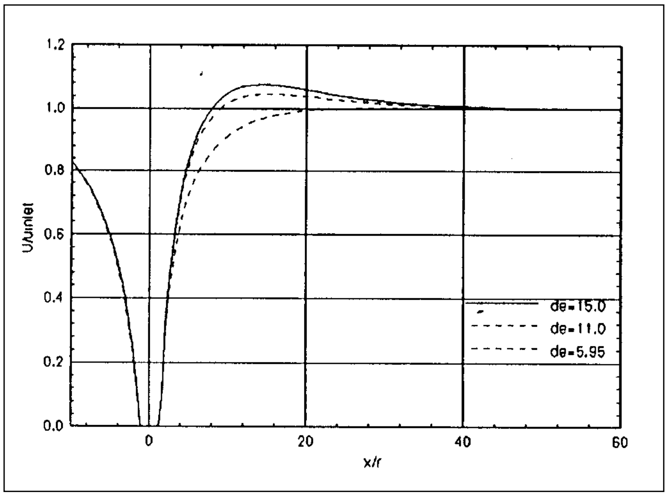



**Fig. 3.2.2.** Velocity along the wake for various *De* wth *w/d* =20.

## 3.3 Mathematical Modelling of Gap-Coupled Microstrip Antenna

Microstrip antenna technology has been one of the most rapidly developing topics in the last fifteen years, receiving the creative attentions of academia and industry throughout the world. As a result of numerous works devoted to this subject over the past two decades, microstrip antennae have become a commercial reality, with applications in wide variety of microwave systems. Rapidly developing market in Personal Communication Systems, Mobile Satellite Communications and Intelligent Vehicle Highway Systems suggest that the demand for microstrip antennae will increase even further.

In the era of *cut-and-try*, designs were done by cutting the materials and then analysing, which is tedious and expensive. Today computers are utilized for modelling and simulating electronic systems which makes the process easier and flexible. But, modelling of microstrip antenna lags far behind because of the presence of an inhomogeneous dielectric, wide variety of feeding techniques and, most importantly, due to the intrinsic sources of errors in the mathematical formulations. The study here is aimed at developing a model for the first-cut design of a gap-coupled rectangular microstrip patch antenna.

The basic microstrip antenna element consists of a strip conductor on a dielectric substrate backed by a ground plane as shown in Fig. 3.3.1. When the patch is excited, charge distributions are established on the underside of the patch metalization and the ground plane. The underside patch is positively charged and the ground plane is negatively charged. The attractive forces between these two oppositely charged sets, try to bind all charges between the plates. But the repulsive positive charge on the patches pushes some of the charges towards the edges, producing a large charge density there, resulting in fringing fields at the ends and thereby radiation. This can be modeled using transmission line or cavity model. The major disadvantage with this class of antennae is its narrow bandwidth. The bandwidth can be improved by increasing the height or using multiple resonators in the

**Fig. 3.3.1.** Geometry of a microstrip patch antenna

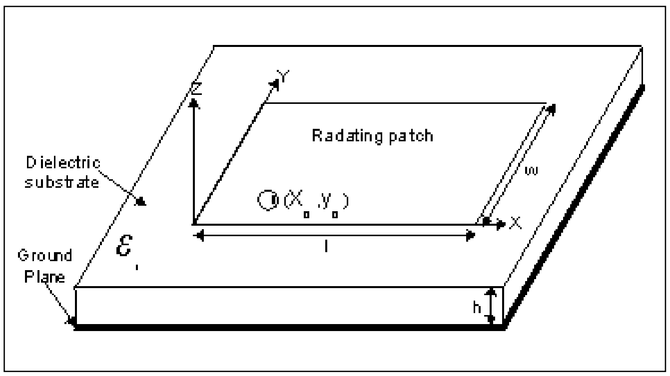
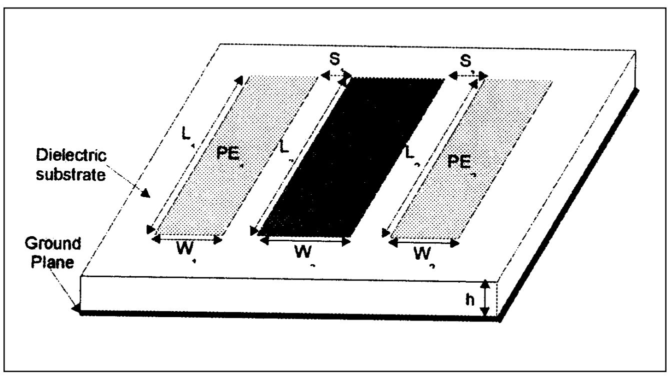



**Fig. 3.3.2.** Geometry of a gap-coupled patch antenna



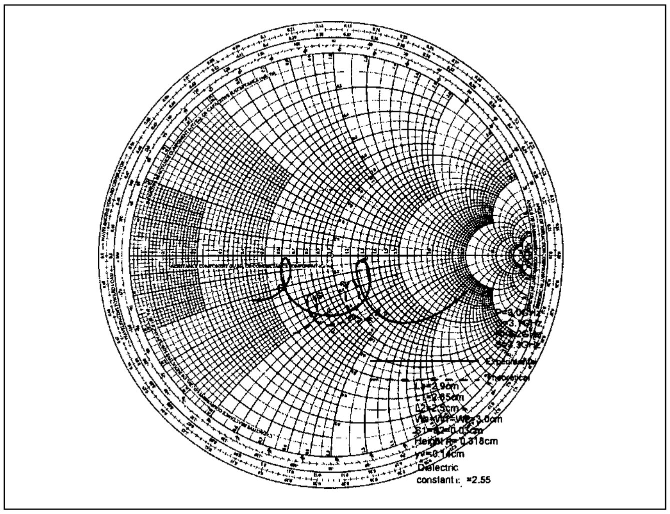


Fig. 3.3.3. Impedance comparison between experimental and the new model

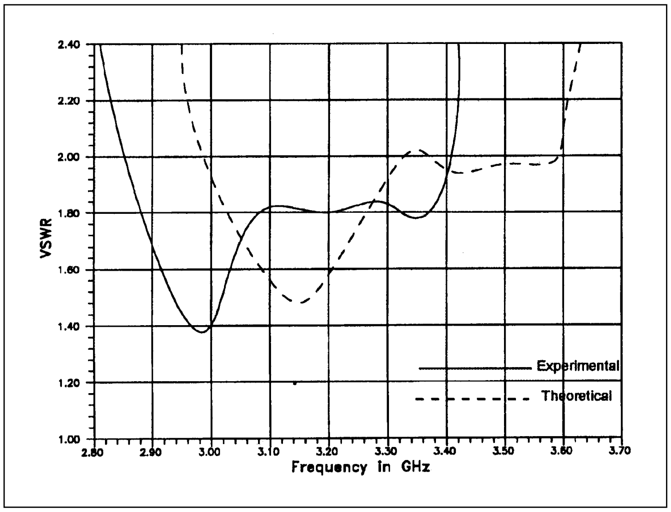



Fig. 3.3.4. Voltage Standing Wave Ratio comparison between experimental and the new model

same plane. There are certain disadvantages associated with increasing height as the unwanted surface wave becomes dominant; the latter method is better.

Figure 3.3.2 shows the geometry of a gap-coupled patch antenna with two parasitic patches at both the radiating edges of the main patch. The electromagnetic field created at the two edges by feeding the central patch excites the parasitic patches and generates electromagnetic field across their edges. The electromagnetic fields from the patches couple with each other to generate an effective radiation. A single excited patch can be represented as a parallel resonant circuit. By using network analysis, the equivalent resonant circuit can be found out if the coupling constants are known. The coupling constants (i.e the electric and magnetic coupling) can be determined by using coupled mode theory for microstrip lines. The constants depend on the dimension and spacing of the patches, height and nature of the substrate.

The input admittance, which is the most important parameter to decide whether the gap-coupled antenna can radiate at a particular frequency, is found out from the iterative equation

$$Y_{aeff}(x,y) = Y_a(x,y) - \sum_{n=1,2} \frac{Y_{mn}^2(x,y)}{2Y_n(0,0) - \dfrac{Y_{mn}^2(0,0)}{Y_a(0,0) + Y_{aeff}(0,0)}}$$

Here, $Y_{aeff}(x,y)$ is the effective admittance of the gap-coupled antenna if the central patch is fed at point $(x,y)$. $Y_a(x,y)$, $Y_1(0,0)$, $Y_2(0,0)$ are the input admittances of the individual patches, without coupling, at the points given in brackets and $Y_{m1}(0,0)$, $Y_{m2}(0,0)$ are the coupling

Fig. 3.3.5. Relative power loss in H plane

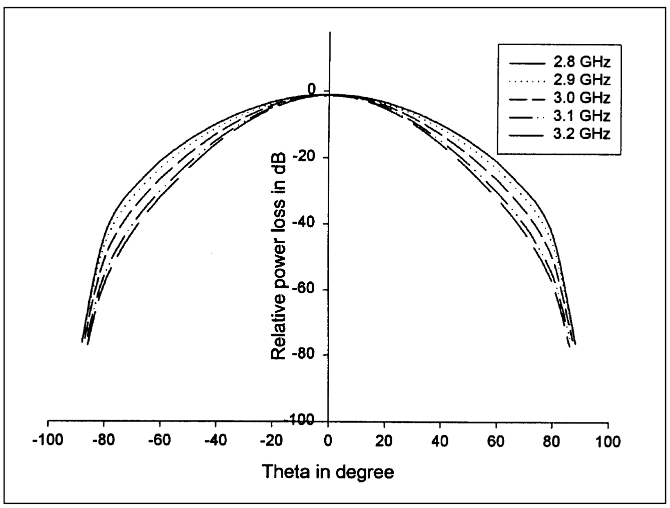
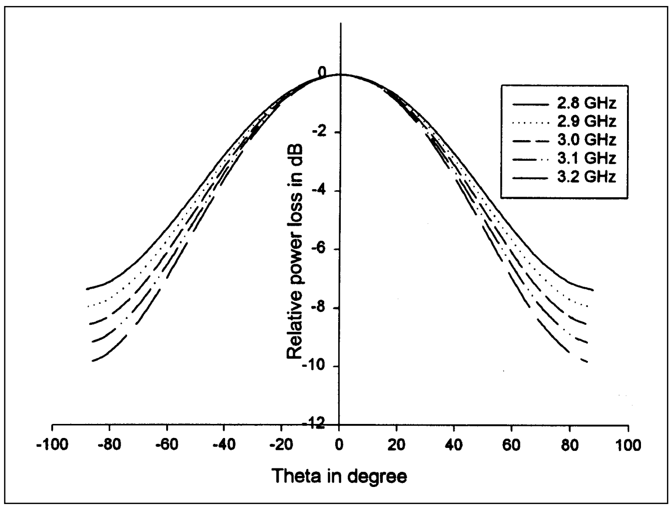



Fig. 3.3.6. Relative power loss in E plane



admittances found out using coupled mode approach and network analysis.

Figure 3.3.3 shows the comparison between the input impedance (reciprocal of input admittance) of the new model and experimental result on a gap-coupled patch antenna with the dimensions indicated. Figure 3.3.4 shows the Voltage Standing Wave Ratio comparison for the same. The relative power loss in H and E planes are shown in Figs. 3.3.5 and 3.3.6.

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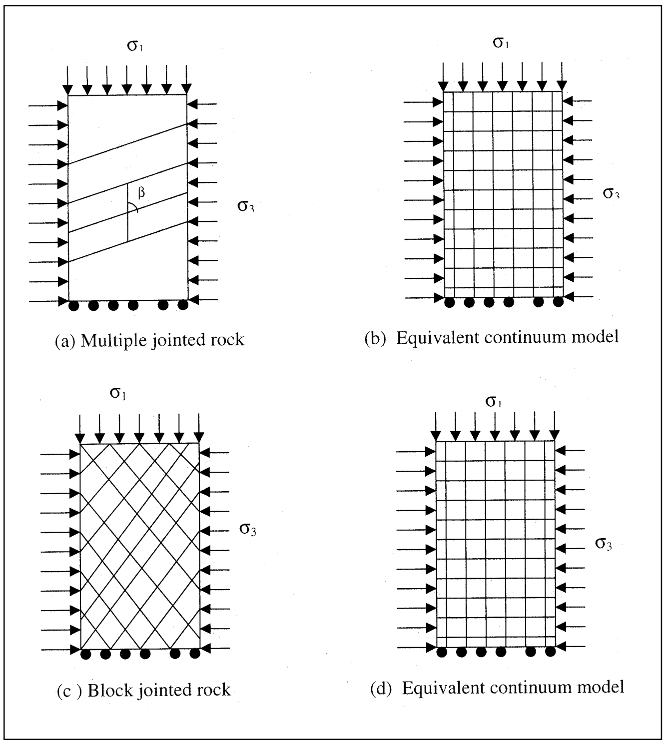
## 3.4 Finite Element Analysis of Discontinuous Medium

Finite element modeling of discontinous media has been carried out by representing the jointed medium as an equivalent continuum with equivalent material properties for obtaining the overall response of the jointed medium. Finite element modeling of jointed rock using the equivalent continuum approach has been carried out by representing the jointed rock properties by a set of empirical relationships. These relationships are derived from the statistical analysis of a large amount of experimental data; they express the properties of jointed rock mass as a function of intact rock properties and joint factor. The major advantage of equivalent continuum approach is that the most complex joint fabric can be represented by a simple finite element mesh as shown in Fig. 3.4.1.

**Fig. 3.4.1.** Jointed rock and the corresponding equivalent continuum finite element model.



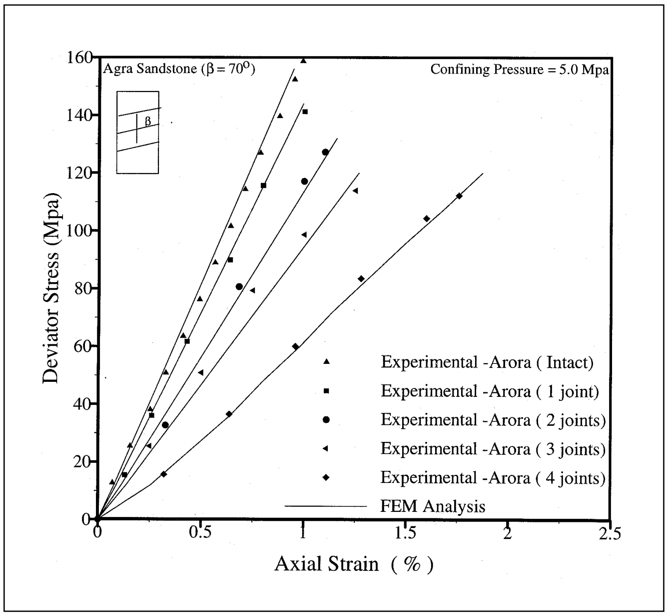




**Fig. 3.4.2.** Stress-strain plot for intact and multiple jointed specimen (experimental data after Arora, 1987).

The equivalent continuum model developed above has been tested and validated for a large amount of test data as well as for a field problem of power cavern excavation for Shiobara power station in Japan. The results are in the form of stress-strain curves. A sample stress-strain plot for multiple jointed specimen of Agra sand stone is shown in Fig. 3.4.2 along with the experimental results. Equivalent continuum model can be applied to field problems, which gives a fair estimate of the displacement behavior of the problem domain in the absence of vast experimental data. The major advantage of this approach is that it can be easily applied to complex field problems without sacrificing accuracy and efficiency. The equivalent continuum model developed above is proposed to be extended to take into account the modeling of discontinuous media in earth's crust by incorporating the relevant rheology.

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## 3.5 Bioremediation

Bioremediation, which exploits the ability of natural organisms to degrade organic contaminants, is an attractive method to clean up oil contamination. Oil and Natural Gas Commission (ONGC) India Ltd., which has

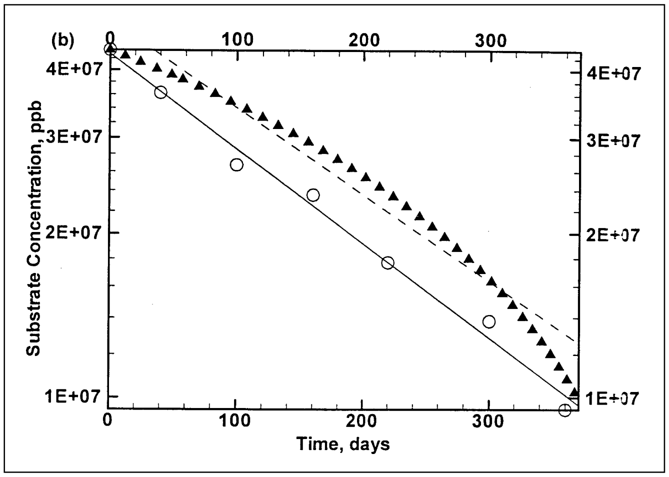


**Fig. 3.5.1.** Circles and exponential fit (soild line) to those points represent the experimental data from RRL, Jorhat while the delta symbols and associated exponential fit (dashed line) represent simulation data. Note that both the regression fits yield exponents of -0.004 but the character of the simulation results exhibits departure from straight line (on a semi-log plot- the mark of exponential nature) behaviour.

many oil fields in Assam under operation, had funded a field pilot study by Regional Research Laboratory (RRL), Jorhat aimed at assessing the potential of the method at Borhola Oil Fields. Laboratory experiments to optimise the parameters for an efficent functional design are not feasible because each laboratory run takes periods of the order of an year. Mathematical models and simulation make the process simpler and realisable. C-MMACS has collaborated with RRL, Jorhat on the latter aspect in the project.

The model employed by us couples partial differential equations (PDEs) and ordinary differential equations (ODEs); PDEs model the diffusion of contaminants in the micropores of soil aggregates and ODEs model the convection in the macropores between the aggregates. Apart from the contaminant, two other variables are employed: oxygen and biomass. Sensitivity studies of the parameters has been carried out and reported earlier.

Borhola oil fields are characterised by high initial contaminant concentrations and we found that the model is computationally expensive for such conditions. Further, some basic defects in the model were highlighted by the high intial contaminant concentrations. Notably, an undue sensitivity to one of the parameters, the ratio of the aggregate micropore liquid volume to the mobile macropore liquid volume ($\varepsilon_m$), was noticed which has been linked to the nature of the boundary conditions employed. Comparison with the laboratory results from RRL, Jorhat, showed that the model reproduces the exponent of the exponential degradation computed from the laboratory data, for comparable values of the parameters. However, the simulation results, when plotted, show noticeable departure from the exponential nature of the curve, as illustrated in Fig. 3.5.1. Based on these findings, modifications are being considered.

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