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Simulation and Experimental Studies on Hydrodynamics Characteristics of Cocurrent Three Phase Fluidisation Using Fuzzy Logic

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ABSTRACT: *Simulation and hydrodynamics studies were carried out in a solid - liquid - gas phase concurrent fluidized bed. The experiment was carried out in a 5.4cm I.D, 6cm O.D and 160cm height vertical Perspex column. Water was used as a continuous phase and air was used as a dispersed phase. Glass beads of diameter 0.2cm, 0.4cm, 0.6cm and Gypsum particle of diameter 0.1201cm, 0.1676cm, 0.2099cm were used as solid for concurrent studies. The column consists of three sections viz. gas liquid disengagement section, test section and gas liquid distributed section. The experiment was conducted with both Glass beads and Gypsum particles on keeping constant gas velocity by varying liquid velocities. The effect of individual phase holdup for various particle sizes with specific liquid flow rates and gas flow rates were studied. Pressure drop in the fluidized bed was measured by using mercury manometer. The individual phase holdups were determined, liquid holdup and solid holdup decreases with increase in liquid velocity whereas gas holdup increases with increases in liquid velocity. With the experimental data, simulation studies were carried out using Fussy Logic.*

Keywords: Simulation, fluidization, hydrodynamic characteristics, mass transfer, gas and liquid holdups.

1.0 INTRODUCTION:

Gas-Liquid-Solid systems are commonly encountered in many of physical processing, chemical, biochemical, electrochemical, petroleum and petrochemical industries [1]. Fluidization is a process by which a bed of suspension of solid particles in gas and liquid achieved by pumping a fluid through a bed upward at a rate sufficient to exert drag force on the particle counteracting their weight[2]. Three phase fluidization is achieved by bubbling gas into a liquid phase and eventually reactive solid is fluidized in liquid phase [3]. Commercial application of three phase fluidization is in heavy oil, synthetic crude processing, and coal liquefaction in the presence of catalyst, biological waste water treatment and fermentation.

The solids used for packing may be either inert or catalyst, depending on the nature of operation. Bed expansion depends on the nature of particles. The bed height increases monotonically as gas velocity increases for large particles. For small particles, decrease of bed size initially exits. The mode of operation of three phase contactor are countercurrent contact [4-11]; cocurrent down flow [11-13]; concurrent up flow [8, 9, 14-15]. The most striking one is cocurrent up flow due to better radial and axial distribution. As liquid hold up is very high, the increase in interfacial area increases the mass transfer.

Our accomplishment in design and operation of a gas-liquid fluidization bed system relies upon the ability to predict the fundamental characteristics of the system. The hydrodynamics, the mixing of individual phases and the heat and mass transfer characteristics can be accurately determined. The superficial velocity at which the drag force is equal to the bed weight is called minimum fluidization velocity. The particles no longer rest on each other. This is the point of fluidization. Commercial gas fluidized beds are usually operated at flow rates many times that required for minimum fluidization, typically 5 to 20 times. Liquid fluidized beds operate at values closer to minimum fluidization velocity. Based on experiment, the various parameters such as pressure drop, bed porosity, gas and liquid holdups were calculated and then simulation studies were done using FUZZY LOGIC.

2.0 MATERIALS AND METHODS

2.1 Experimental Studies

2.1.1 Experimental Setup:

The Perspex fluidized bed column used was of 5.4cm I.D, 6 cm O.D and 160cm height as shown in figure1. The liquid and gas flow rate were measured. The gas and liquid streams were merged and passed through a quick closing valve, a 0.3cm thick perforated grid before entering the bed. The calming section and the grid ensured that the liquid and the gas were well mixed and evenly distributed into the particles. A tee joint at the top of the column allowed gas to escape and liquid to be recirculated to the reservoir. Pressure tapping were provided at the top and bottom of the test section.

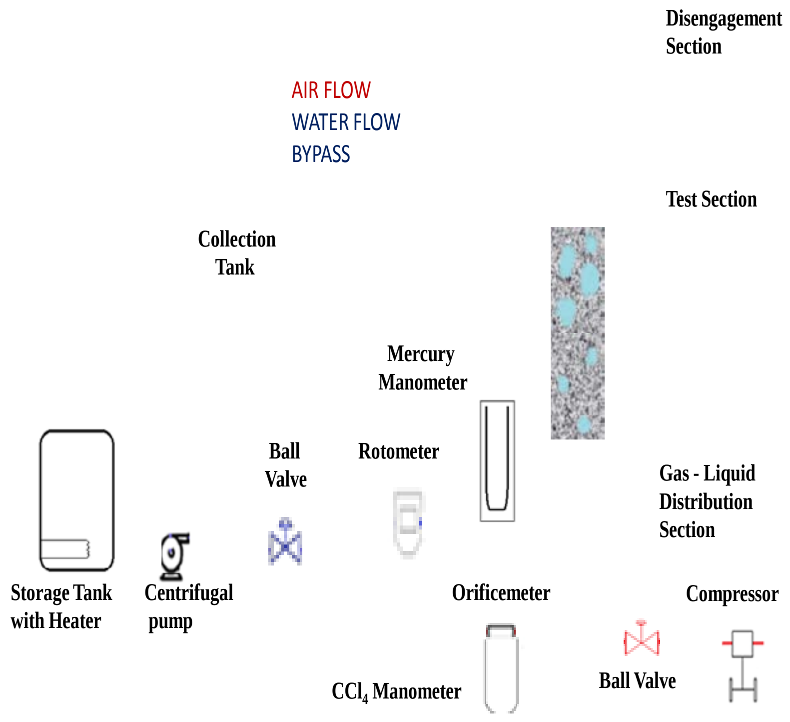

Fig. 1 Schematic Diagram of the Experimental Setup

2.1.2 Experimental Procedure

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.127	0.2986	0.7014	0.0157	0.2828	10926.41	33.269	47.431	0.2058	0.2934
2.43	0.139	0.3591	0.6409	0.1007	0.2584	11501.0	66.538	103.826	0.2058	0.3212
3.64	0.150	0.4061	0.5939	0.1667	0.2395	11744.0	99.807	168.064	0.2058	0.3466
4.85	0.177	0.4967	0.5033	0.2938	0.2029	12165.39	133.076	264.420	0.2058	0.4090
6.07	0.201	0.5568	0.4432	0.3781	0.1787	12506.28	166.345	375.342	0.2058	0.4644
7.28	0.300	0.7031	0.2969	0.5833	0.1197	13042.59	199.614	672.255	0.2058	0.6931

The experiment is performed by passing water and gas through the bed of solids. The flow rates of both gas and liquid are regulated by the control valves. The liquid flow rate, manometer readings and the bed heights are observed. The gas velocity is kept constant and the liquid velocity is varied. After steady state is attained for each liquid velocity the fluidized bed height and manometer readings are noted. The same procedure is repeated for four different gas velocities. The effect on phase hold up, pressure drop and the bed porosity is studied for different sizes of glass and gypsum particles at 35˚C.

2.1.3 FUZZY LOGIC

A fuzzy logic (FL)-based expert system (ES) works based on the principle of fuzzy set theory, and it is a potential tool for dealing with imprecision and uncertainty[18,19]. The FL-based ESs has been developed by various researchers, after realizing their potential in solving real world complex problems. The performance of an ES mainly depends on its KB, which consists of a data base and a rule base. Thus, designing a proper KB is very important, which is difficult too. In this paper fuzzy logic is used to predict gas holdup and liquid holdup for glass beads and gypsum particles for different sizes with varying liquid flow rates by keeping the gas flow to be constant.

3.0 RESULTS AND DISCUSSION

The hydrodynamic parameters of interest in a three phase fluidized bed are: bed porosity (ε), solid holdup (ε_s), gas holdup (ε_g), Liquid holdup (ε_l) and fluidized bed pressure drop (ΔP) were calculated using experimental data for both glass beads and gypsum particles. The hydrodynamic characteristics like gas holdup and liquid holdup were predicted using fuzzy logic.

TABULATION FOR GLASS BEADS

Hydrodynamic characteristics for dp = 0.2cm, Ug = 0.169851cm/s

Hydrodynamic characteristics for dp = 0.2cm, Ug = 0.212314 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.140	0.363716	0.6363	0.0714	0.29229	9668.506	33.269	52.286	0.2573	0.4043
2.43	0.160	0.443252	0.5567	0.1875	0.25575	10094.29	66.538	119.512	0.2573	0.4621
3.64	0.200	0.554601	0.4454	0.3500	0.20460	10644.07	99.807	224.085	0.2573	0.5776
4.85	0.250	0.643681	0.3563	0.4800	0.16368	11128.54	133.076	373.475	0.2573	0.7220
6.07	0.276	0.677247	0.3228	0.5290	0.14826	11420.4	166.345	515.395	0.2573	0.7971
7.28	0.304	0.706975	0.2930	0.5724	0.13461	11707.7	199.614	681.218	0.2573	0.8780

Hydrodynamic characteristics for dp = 0.2 cm, Ug = 0.304317 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.141	0.36823	0.631771	0.049645	0.3185836	8247.7	33.269	52.660	0.3688	0.5837

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.131	0.3169	0.683065	0.00763	0.30930	10034.61	66.5381	97.411	0.4116	0.6026
2.43	0.135	0.3372	0.662826	0.03704	0.30014	10351.82	133.0762	200.771	0.4116	0.6210
3.64	0.145	0.3829	0.617114	0.10345	0.27944	10734.22	199.6142	323.464	0.4116	0.6670
4.85	0.160	0.4407	0.559259	0.18750	0.25324	11118.55	266.1523	475.902	0.4116	0.7360
6.07	0.174	0.4857	0.514261	0.25287	0.23287	11456.78	332.6904	646.929	0.4116	0.8004
7.28	0.196	0.5435	0.456538	0.33673	0.20673	11802.14	399.2285	874.469	0.4116	0.9016
2.43	0.173	0.48509	0.514912	0.225434	0.2596548	8716.4	66.538	129.222	0.3688	0.7162
3.64	0.242	0.63190	0.36810	0.446281	0.1856210	9268.3	99.807	271.143	0.3688	1.0018
4.85	0.288	0.69070	0.30930	0.534722	0.1559732	9577.7	133.076	430.243	0.3688	1.1922
6.07	0.325	0.72591	0.274091	0.587692	0.1382163	9997.6	166.345	606.897	0.3688	1.3454
7.28	0.355	0.74907	0.250929	0.622535	0.126536	10408.8	199.614	795.502	0.3688	1.4696

Hydrodynamic characteristics for dp = 0.2 cm, Ug = 0.346779 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.153	0.41778	0.58222	0.052288	0.365492	7866.8	33.269	57.142	0.4202	0.7217
2.43	0.205	0.56546	0.43454	0.292683	0.2727819	8494.1	66.538	153.125	0.4202	0.9670
3.64	0.260	0.65739	0.34261	0.442308	0.215078	8984.7	99.807	291.310	0.4202	1.2265
4.85	0.320	0.72163	0.27837	0.546875	0.1747509	9435.0	133.076	478.048	0.4202	1.5095
6.07	0.379	0.76496	0.23504	0.617410	0.1475470	9732.7	166.345	707.735	0.4202	1.7878
7.28	0.416	0.78587	0.21413	0.651440	0.1344240	10275.4	199.614	932.193	0.4202	1.9624

Hydrodynamic characteristics for dp = 0.4cm, Ug = 0.169851cm/s

Hydrodynamic characteristics for dp = 0.4cm, Ug = 0.212314 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.137	0.3469	0.653149	0.01460	0.33225	10172.90	66.5381	101.873	0.5145	0.7878
2.43	0.147	0.3913	0.608717	0.08163	0.30965	11185.92	133.0762	218.617	0.5145	0.8453
3.64	0.168	0.4674	0.532628	0.19643	0.27094	11114.19	199.6142	374.772	0.5145	0.9661
4.85	0.190	0.5290	0.470955	0.28947	0.23957	11737.82	266.1523	565.133	0.5145	1.0926
6.07	0.216	0.5857	0.414266	0.37500	0.21073	12080.23	332.6904	803.084	0.5145	1.2421
7.28	0.256	0.6505	0.349537	0.47266	0.17781	12420.11	399.2285	1142.164	0.5145	1.4721

Hydrodynamic characteristics for dp = 0.4 cm, Ug = 0.304317 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.139	0.3562	0.643752	0.01439	0.34186	7442.59	66.5381	103.360	0.7375	1.1457
2.43	0.159	0.4372	0.562777	0.13836	0.29886	7984.40	133.0762	236.464	0.7375	1.3105
3.64	0.185	0.5163	0.483684	0.25946	0.25686	8355.85	199.6142	412.696	0.7375	1.5248
4.85	0.202	0.5570	0.442978	0.32178	0.23524	8662.08	266.1523	600.826	0.7375	1.6649
6.07	0.227	0.6058	0.394192	0.39648	0.20933	8972.33	332.6904	843.982	0.7375	1.8710
7.28	0.265	0.6623	0.337666	0.48302	0.17932	9284.21	399.2285	1182.318	0.7375	2.1842

Hydrodynamic characteristics for dp = 0.4 cm, Ug = 0.346779 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.126	0.27919	0.72081	0.00794	0.27125	12640.50	99.807	138.465	0.6175	0.8566
2.43	0.127	0.28487	0.71513	0.01575	0.26912	12915.60	199.614	279.128	0.6175	0.8634
3.64	0.128	0.29045	0.70955	0.02344	0.26702	12941.38	299.421	421.989	0.6175	0.8702
4.85	0.131	0.30670	0.69330	0.04580	0.26090	13261.24	399.228	575.840	0.6175	0.8906
6.07	0.141	0.35587	0.64413	0.11348	0.24240	13563.31	499.036	774.746	0.6175	0.9586
7.28	0.159	0.42879	0.57121	0.21384	0.21496	14008.05	598.843	1048.380	0.6175	1.0810

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.143	0.3743	0.625745	0.02797	0.34628	7338.32	66.5381	106.334	0.8404	1.3431
2.43	0.160	0.4407	0.559259	0.13125	0.30949	7972.92	133.0762	237.951	0.8404	1.5027
3.64	0.182	0.5083	0.491656	0.23626	0.27208	8331.91	199.6142	406.004	0.8404	1.7094
4.85	0.211	0.5759	0.424083	0.34123	0.23468	8671.77	266.1523	627.595	0.8404	1.9817
6.07	0.235	0.6192	0.380772	0.40851	0.21072	8975.87	332.6904	873.726	0.8404	2.2072
7.28	0.269	0.6674	0.332645	0.48327	0.18408	9280.68	399.2285	1200.164	0.8404	2.5265

Hydrodynamic characteristics for dp = 0.6 cm, Ug = 0.169851cm/s

Hydrodynamic characteristics for dp = 0.6 cm, Ug = 0.212314 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.128	0.29045	0.70955	0.00781	0.28264	10160.75	99.807	140.663	0.7718	1.0878
2.43	0.134	0.32222	0.67778	0.05224	0.26998	10769.84	199.614	294.513	0.7718	1.1388
3.64	0.143	0.36488	0.63512	0.11189	0.25299	11017.74	299.421	471.441	0.7718	1.2152
4.85	0.161	0.43589	0.56411	0.21118	0.22471	11168.67	399.228	707.712	0.7718	1.3682
6.07	0.176	0.48397	0.51603	0.27841	0.20556	11374.99	499.036	967.059	0.7718	1.4957
7.28	0.185	0.50907	0.49093	0.31351	0.19556	11669.15	598.843	1219.813	0.7718	1.5722

Hydrodynamic characteristics for dp = 0.6 cm, Ug = 0.304317 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.132	0.31195	0.68805	0.01515	0.29680	8812.73	99.807	145.059	1.1063	1.6079
2.43	0.140	0.35127	0.64873	0.07143	0.27984	9171.20	199.614	307.701	1.1063	1.7053
3.64	0.153	0.40639	0.59361	0.15033	0.25607	9544.34	299.421	504.409	1.1063	1.8636
4.85	0.164	0.44621	0.55379	0.20732	0.23889	9870.00	399.228	720.899	1.1063	1.9976
6.07	0.176	0.48397	0.51603	0.26136	0.22260	10313.41	499.036	967.059	1.1063	2.1438
7.28	0.190	0.52199	0.47801	0.31579	0.20620	10623.18	598.843	1252.781	1.1063	2.3143

Hydrodynamic characteristics for dp = 0.6 cm, Ug = 0.346779 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.135	0.32724	0.67276	0.00741	0.31984	8918.64	99.807	148.356	1.2606	1.8738
2.43	0.145	0.37364	0.62636	0.07586	0.29778	9547.87	199.614	318.690	1.2606	2.0126

3.64	0.157	0.42152	0.57848	0.14650	0.27502	9909.10	299.421	517.596	1.2606	2.1792
4.85	0.175	0.48102	0.51898	0.23429	0.24673	10528.86	399.228	769.252	1.2606	2.4291
6.07	0.192	0.52697	0.47303	0.30208	0.22489	10856.29	499.036	1054.974	1.2606	2.6650

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.161	0.26766	0.73234	0.00621	0.26145	11520.42581	19.978	27.280	0.1236	0.1688
2.43	0.166	0.28972	0.71028	0.03614	0.25357	11862.29315	39.956	56.254	0.1236	0.1740
3.64	0.175	0.32625	0.67375	0.08571	0.24053	12242.58554	59.934	88.956	0.1236	0.1834
4.85	0.210	0.43854	0.56146	0.23810	0.20044	12636.68143	79.912	142.329	0.1236	0.2201
6.07	0.258	0.54300	0.45700	0.37984	0.16315	12916.87748	99.890	218.577	0.1236	0.2704
7.28	0.303	0.61087	0.38913	0.47195	0.13892	13380.98721	119.868	308.041	0.1236	0.3176

7.28	0.224	0.59454	0.40546	0.40179	0.19276	11200.80	598.843	1476.963	1.2606	3.1092

TABULATION FOR GYPSUM PARTICLES

Hydrodynamic characteristics for dp = 0.1201 cm, Ug = 0.169851cm/s

Hydrodynamic characteristics for dp = 0.1201 cm, Ug = 0.212314 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.163	0.27665	0.72335	0.00613	0.27051	10528.56799	19.978	27.619	0.1545	0.2136
2.43	0.170	0.30643	0.69357	0.04706	0.25937	11012.9652	39.956	57.609	0.1545	0.2227
3.64	0.183	0.35570	0.64430	0.11475	0.24095	11538.47637	59.934	93.022	0.1545	0.2398
4.85	0.210	0.43854	0.56146	0.22857	0.20997	12100.98343	79.912	142.329	0.1545	0.2752
6.07	0.241	0.51076	0.48924	0.32780	0.18296	12471.37753	99.890	204.175	0.1545	0.3158
7.28	0.306	0.61468	0.38532	0.47059	0.14410	12718.42691	119.868	311.091	0.1545	0.4009

Hydrodynamic characteristics for dp = 0.1201 cm, Ug = 0.304317 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.166	0.28972	0.71028	0.00602	0.28369	9288.900796	19.978	28.127	0.2214	0.3118
2.43	0.178	0.33760	0.66240	0.07303	0.26457	9683.488244	39.956	60.320	0.2214	0.3343
3.64	0.215	0.45160	0.54840	0.23256	0.21904	10293.83779	59.934	109.289	0.2214	0.4038
4.85	0.274	0.56968	0.43032	0.39781	0.17187	10567.37959	79.912	185.706	0.2214	0.5146
6.07	0.321	0.63269	0.36731	0.48598	0.14671	10884.83625	99.890	271.950	0.2214	0.6029
7.28	0.374	0.68474	0.31526	0.55882	0.12592	11186.91499	119.868	380.222	0.2214	0.7024

Hydrodynamic characteristics for dp = 0.1201 cm, Ug = 0.346779 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.172	0.31450	0.68550	0.02326	0.29124	10571.49691	19.978	29.144	0.2523	0.3681
2.43	0.195	0.39535	0.60465	0.13846	0.25689	10800.5935	39.956	66.081	0.2523	0.4173
3.64	0.252	0.53212	0.46788	0.33333	0.19878	11289.14926	59.934	128.096	0.2523	0.5393

4.85	0.317	0.62805	0.37195	0.47003	0.15802	11654.56398	79.912	214.849	0.2523	0.6784
6.07	0.386	0.69454	0.30546	0.56477	0.12978	12105.53454	99.890	327.018	0.2523	0.8261
7.28	0.422	0.72060	0.27940	0.60190	0.11870	12388.98308	119.868	429.021	0.2523	0.9031

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.191	0.37148	0.62852	0.00524	0.36625	14978.2	27.8795	44.3575	0.1725	0.2744
2.43	0.196	0.38752	0.61248	0.03061	0.35690	15303.6	55.7589	91.0373	0.1725	0.2816
3.64	0.210	0.42835	0.57165	0.09524	0.33311	15727.3	83.6384	146.3099	0.1725	0.3017
4.85	0.231	0.48032	0.51968	0.17749	0.30283	16161.3	111.5178	214.5879	0.1725	0.3319
6.07	0.264	0.54528	0.45472	0.28030	0.26497	16597.7	139.3973	306.5541	0.1725	0.3793
7.28	0.300	0.59984	0.40016	0.36667	0.23318	16979.2	167.2767	418.0284	0.1725	0.4310

Hydrodynamic characteristics for dp = 0.1676 cm, Ug = 0.169851cm/s

Hydrodynamic characteristics for dp = 0.1676 cm, Ug = 0.212314 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.196	0.38752	0.61248	0.01020	0.37731	13134.0	27.8795	45.5186	0.2156	0.3520
2.43	0.210	0.42835	0.57165	0.07619	0.35216	13541.5	55.7589	97.5400	0.2156	0.3771
3.64	0.227	0.47116	0.52884	0.14537	0.32578	13932.5	83.6384	158.1541	0.2156	0.4077
4.85	0.254	0.52737	0.47263	0.23622	0.29115	14338.1	111.5178	235.9538	0.2156	0.4562
6.07	0.286	0.58026	0.41974	0.32168	0.25858	14712.5	139.3973	332.1003	0.2156	0.5136
7.28	0.345	0.65204	0.34796	0.43768	0.21436	15233.1	167.2767	480.7326	0.2156	0.6196

Hydrodynamic characteristics for dp = 0.1676 cm, Ug = 0.304317 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.200	0.39977	0.60023	0.01500	0.38477	11285.4	27.8795	46.4476	0.3090	0.5148
2.43	0.225	0.46646	0.53354	0.12444	0.34201	11741.4	55.7589	104.5071	0.3090	0.5792
3.64	0.250	0.51981	0.48019	0.21200	0.30781	12252.3	83.6384	174.1785	0.3090	0.6435
4.85	0.293	0.59028	0.40972	0.32765	0.26264	12519.2	111.5178	272.1829	0.3090	0.7542
6.07	0.330	0.63622	0.36378	0.40303	0.23319	12853.1	139.3973	383.1927	0.3090	0.8495
7.28	0.404	0.70285	0.29715	0.51238	0.19048	13206.9	167.2767	562.9449	0.3090	1.0400

Hydrodynamic characteristics for dp = 0.1676 cm, Ug = 0.346779 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.205	0.41441	0.58559	0.02439	0.39002	10683.2	27.8795	47.6088	0.3521	0.6013
2.43	0.228	0.47348	0.52652	0.12281	0.35067	11608.5	55.7589	105.9005	0.3521	0.6688
3.64	0.259	0.53650	0.46350	0.22780	0.30870	11884.6	83.6384	180.4489	0.3521	0.7597

4.85	0.304	0.60511	0.39489	0.34211	0.26300	12399.8	111.5178	282.4014	0.3521	0.8917
6.07	0.362	0.66838	0.33162	0.44751	0.22086	12757.7	139.3973	420.3508	0.3521	1.0619
7.28	0.446	0.73084	0.26916	0.55157	0.17927	13101.2	167.2767	621.4689	0.3521	1.3083

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.206	0.3854738	0.614526	0.004854	0.380619	13862.47	34.9159	56.8175	0.2160	0.3515
2.43	0.207	0.3884425	0.611558	0.009662	0.378781	14123.67	69.8317	114.1867	0.2160	0.3532
3.64	0.210	0.3971790	0.602821	0.023810	0.373369	14411.14	104.7476	173.7623	0.2160	0.3583
4.85	0.221	0.4271837	0.572816	0.072398	0.354785	14785.70	139.6634	243.8189	0.2160	0.3771
6.07	0.247	0.4874801	0.512520	0.170040	0.317440	15246.25	174.5793	340.6293	0.2160	0.4215
7.28	0.280	0.5478843	0.452116	0.267857	0.280027	15795.49	209.4951	463.3662	0.2160	0.4778

Hydrodynamic characteristics for dp = 0.2099 cm, Ug = 0.169851cm/s

Hydrodynamic characteristics for dp = 0.2099 cm, Ug = 0.212314 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.209	0.3942947	0.605705	0.004785	0.389510	12129.22	34.9159	57.6450	0.2700	0.4458
2.43	0.220	0.4245800	0.575420	0.054545	0.370035	12490.25	69.8317	121.3578	0.2700	0.4692
3.64	0.237	0.4658548	0.534145	0.122363	0.343492	12873.58	104.7476	196.1032	0.2700	0.5055
4.85	0.255	0.5035592	0.496441	0.184314	0.319245	12721.99	139.6634	281.3295	0.2700	0.5439
6.07	0.280	0.5478843	0.452116	0.257143	0.290741	13079.24	174.5793	386.1385	0.2700	0.5972
7.28	0.316	0.5993911	0.400609	0.341772	0.257619	13438.02	209.4951	522.9419	0.2700	0.6740

Hydrodynamic characteristics for dp = 0.2099 cm, Ug = 0.304317 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.213	0.4056695	0.594331	0.014085	0.391585	10662.96	34.9159	58.7482	0.3870	0.6512

2.43	0.228	0.4447701	0.555230	0.078947	0.365823	10782.75	69.8317	125.7708	0.3870	0.6970
3.64	0.249	0.4915968	0.508403	0.156627	0.334970	11281.41	104.7476	206.0325	0.3870	0.7612
4.85	0.277	0.5429877	0.457012	0.241877	0.301110	11263.55	139.6634	305.6010	0.3870	0.8468
6.07	0.306	0.5862993	0.413701	0.313725	0.272574	11340.50	174.5793	421.9942	0.3870	0.9355
7.28	0.345	0.6330655	0.366935	0.391304	0.241761	11411.77	209.4951	570.9334	0.3870	1.0547

Hydrodynamic characteristics for dp = 0.2099 cm, Ug = 0.346779 cm/s

U_l	L_f	ε	ε_s	ε_g	ε_l	ΔP	$N_{Re,p,liq}$	$N_{Re,m,liq}$	$N_{Re,p,gas}$	$N_{Re,m,gas}$
1.21	0.216	0.4139240	0.586076	0.018519	0.395406	9926.85	34.9159	59.5757	0.4410	0.7525
2.43	0.234	0.4590068	0.540993	0.094017	0.364990	10303.08	69.8317	129.0806	0.4410	0.8152
3.64	0.256	0.5054984	0.494502	0.171875	0.333623	10665.16	104.7476	211.8245	0.4410	0.8918
4.85	0.286	0.5573692	0.442631	0.258741	0.298628	11023.30	139.6634	315.5303	0.4410	0.9963
6.07	0.331	0.6175456	0.382454	0.359517	0.258029	11251.58	174.5793	456.4709	0.4410	1.1531
7.28	0.383	0.6694715	0.330528	0.446475	0.222996	11583.81	209.4951	633.8188	0.4410	1.3343

3.1 BED POROSITY (ε)

The results indicate that the expanded bed voidage depends on phase velocities, properties of solids and the other two phases. As the gas phase Modified Reynolds number increases the bed voidage increases; the increase is high at low Modified Reynolds number, whereas it is less at higher Modified Reynolds numbers as shown in the figures. Higher flow rates of the phases lead to larger bed expansion which in turn increases the bed voidage. Miura *et al* (2001) reported increase of bed voidage with increase in superficial liquid velocities and superficial gas velocities. The influence of phase flow rates on ε seems to be considerable at low Modified Reynolds numbers, where it is marginal at high Modified Reynolds numbers.

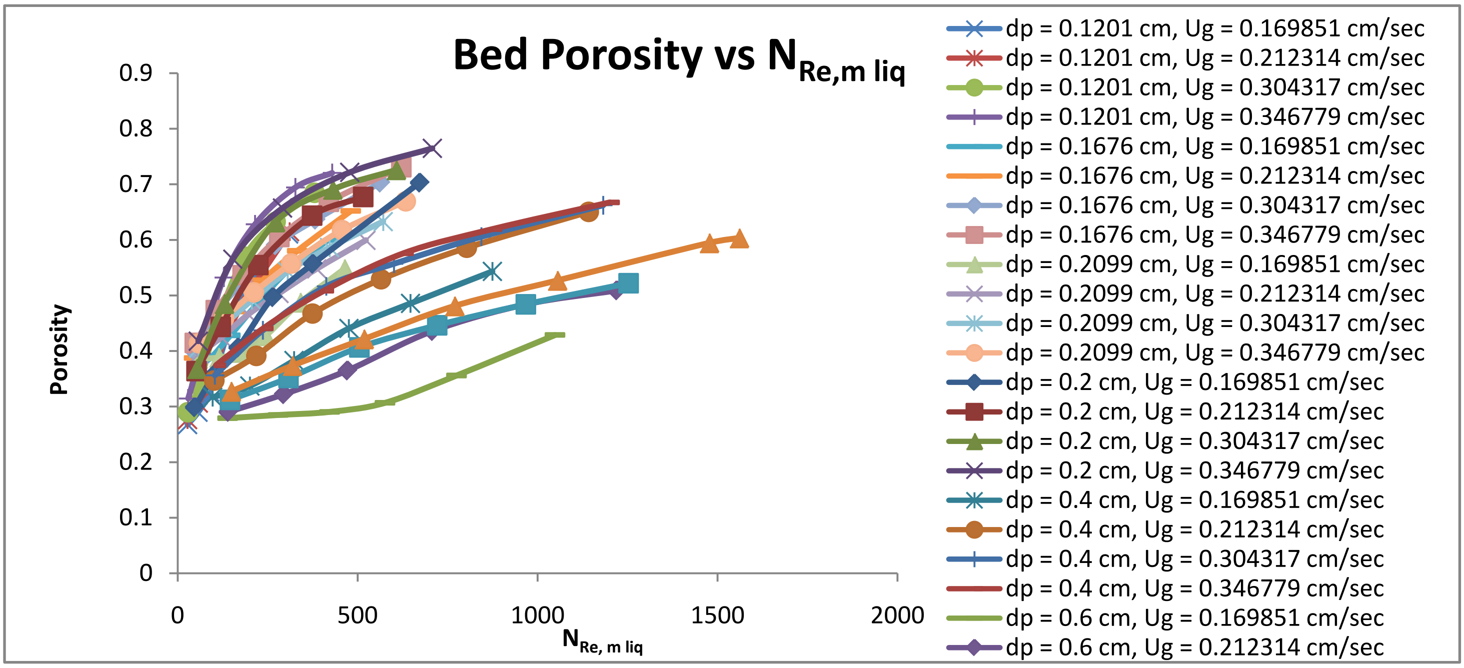

Figure 3.1 Porosity vs $N_{Re,\, m\, liq}$

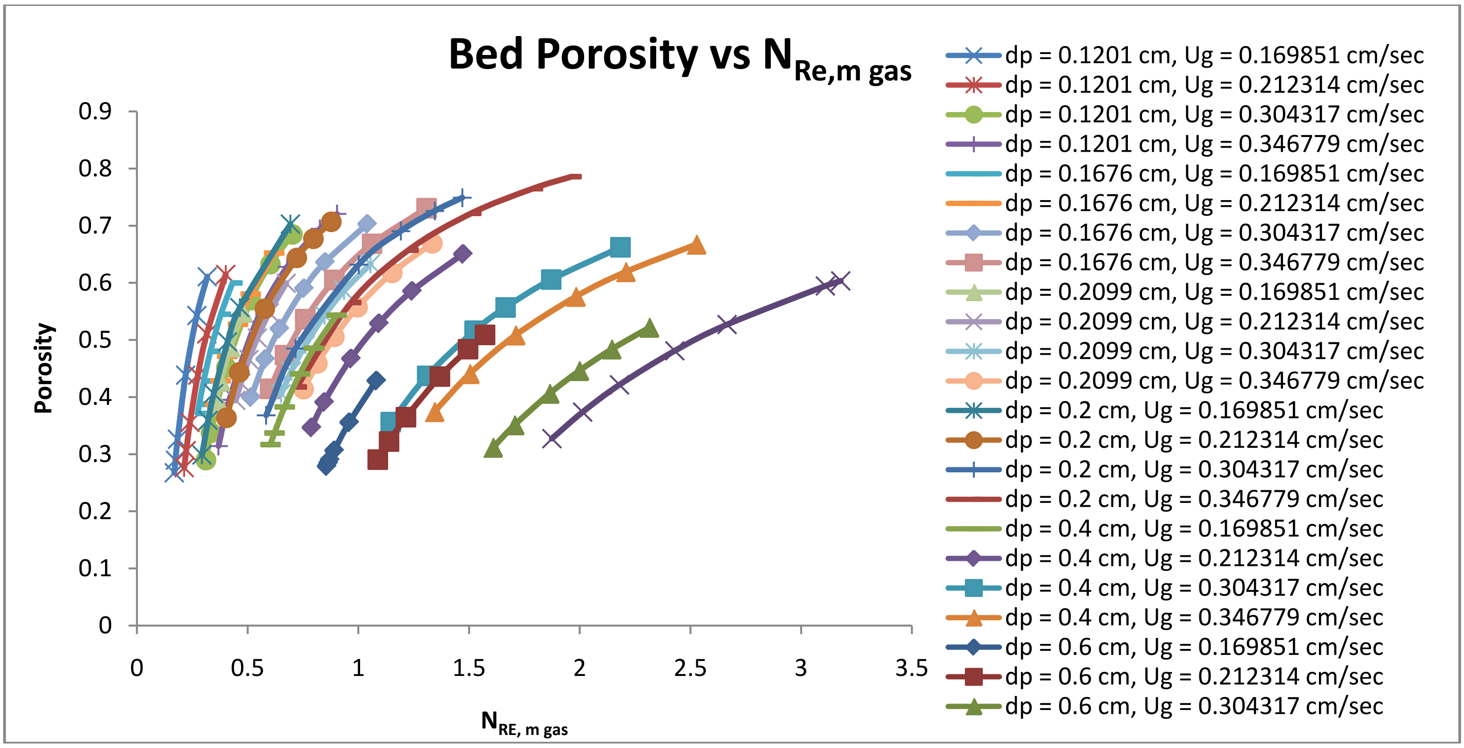

Figure 3.2 Porosity vs $N_{Re,\, m\, gas}$

3.2 SOLID HOLDUP (ε_s)

It has been observed that ε_s decreases steeply as the gas phase Modified Reynolds number increases as well as liquid phase Modified Reynolds number increases. Ik-Sang Shin *et al* (2007) reported similar trends. These trends may be explained as follows; when either liquid velocity or gas velocity is increased, there would be higher drag forces exerted on the solid particles, leading to more bed expansion; this results in reduction of solids holdup in the expanded bed. However, the decrease is considerable at low Modified Reynolds numbers and ε_s seem to be approaching a constant value at high gas phase Modified Reynolds numbers.

Since ε_s = (1- ε) and ε increase with Modified Reynolds number (gas or liquid) as explained in section 1, ε_s should decrease with an increase in Modified Reynolds number.

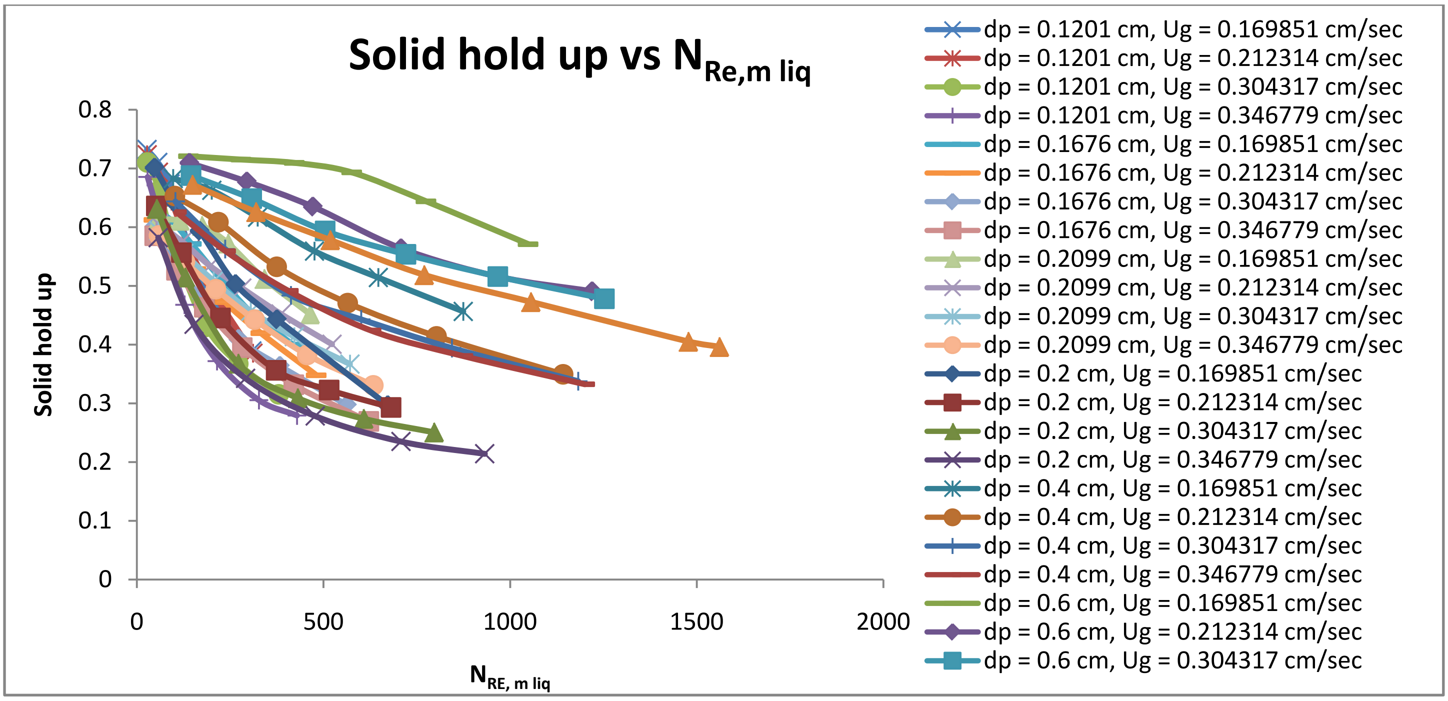

Figure 3.3 Solid vs $N_{Re,\ m\ liq}$

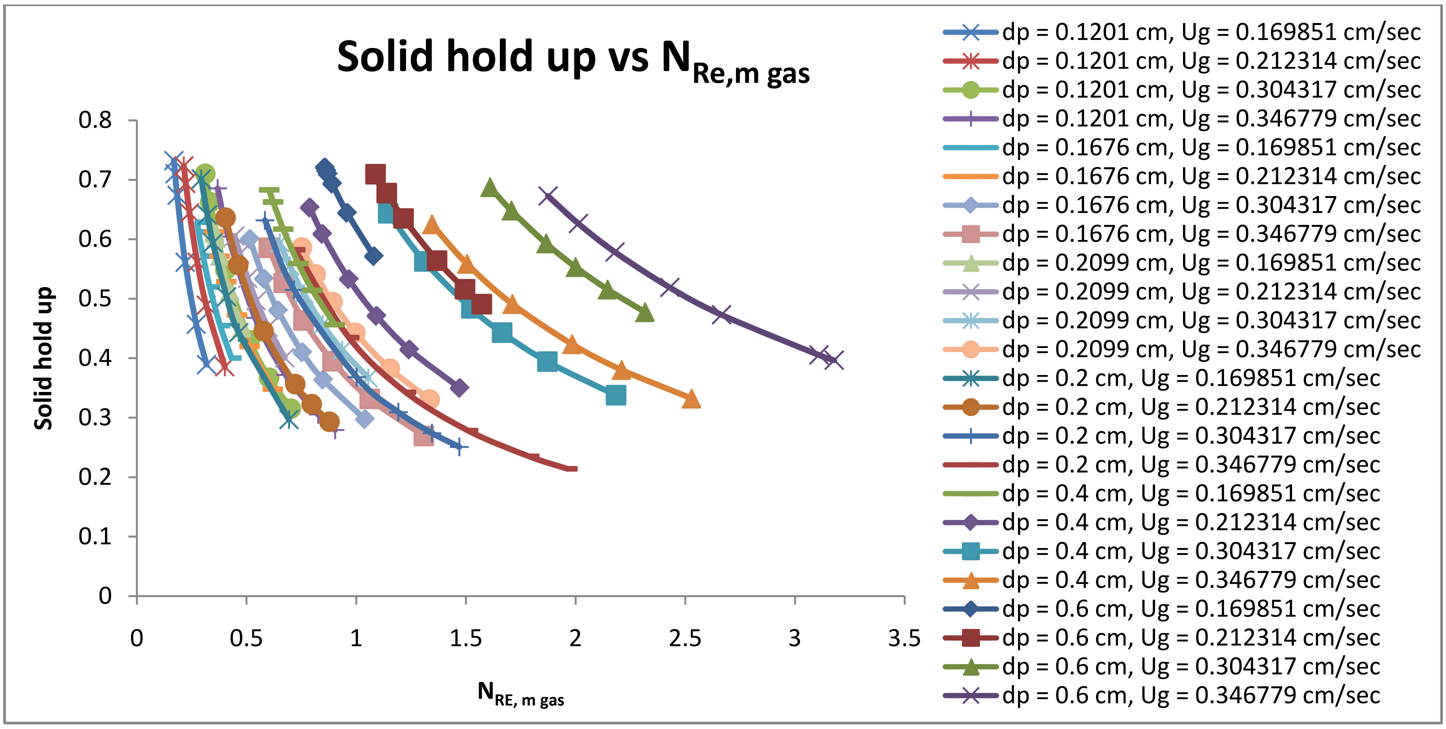

Figure 3.4 Solid vs $N_{Re,\ m\ gas}$

3.3 GAS HOLDUP (ε_g)

The gas holdups are found to be increasing with the increase in gas phase Modified Reynolds number and also with the increasing liquid phase Modified Reynolds number as shown in the figures; this increase is higher at low Modified Reynolds number (gas or liquid) and approaching a constant value at higher Modified Reynolds number. The gas and liquid phases are moving cocurrently through the column; however the liquid phase velocities are higher than gas phase velocities obtained in this work. So, since the gas passage through the column is slower, more gas accumulation occurs in the column compared to liquid accumulation resulting in an increase in the gas holdup, gas holdup vs Modified Reynolds number follows similar trends for all the temperatures. The influence of temperature on phase properties causes a slight decrease of ε_g with an increase in temperature

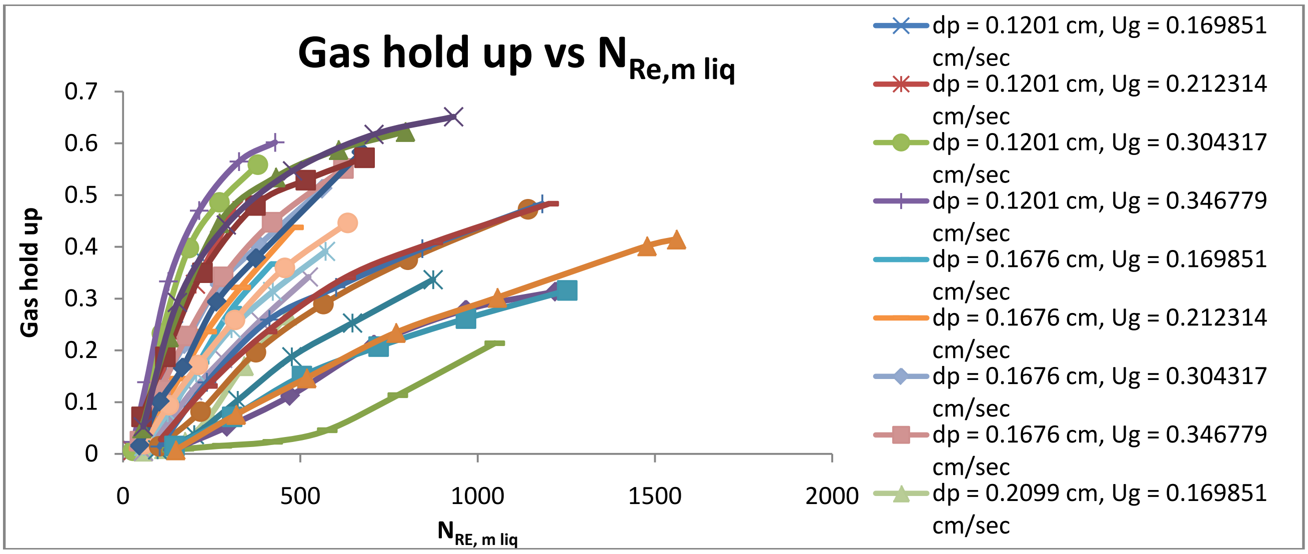

Figure 3.5 Gas holdup vs $N_{Re,\ m\ liq}$

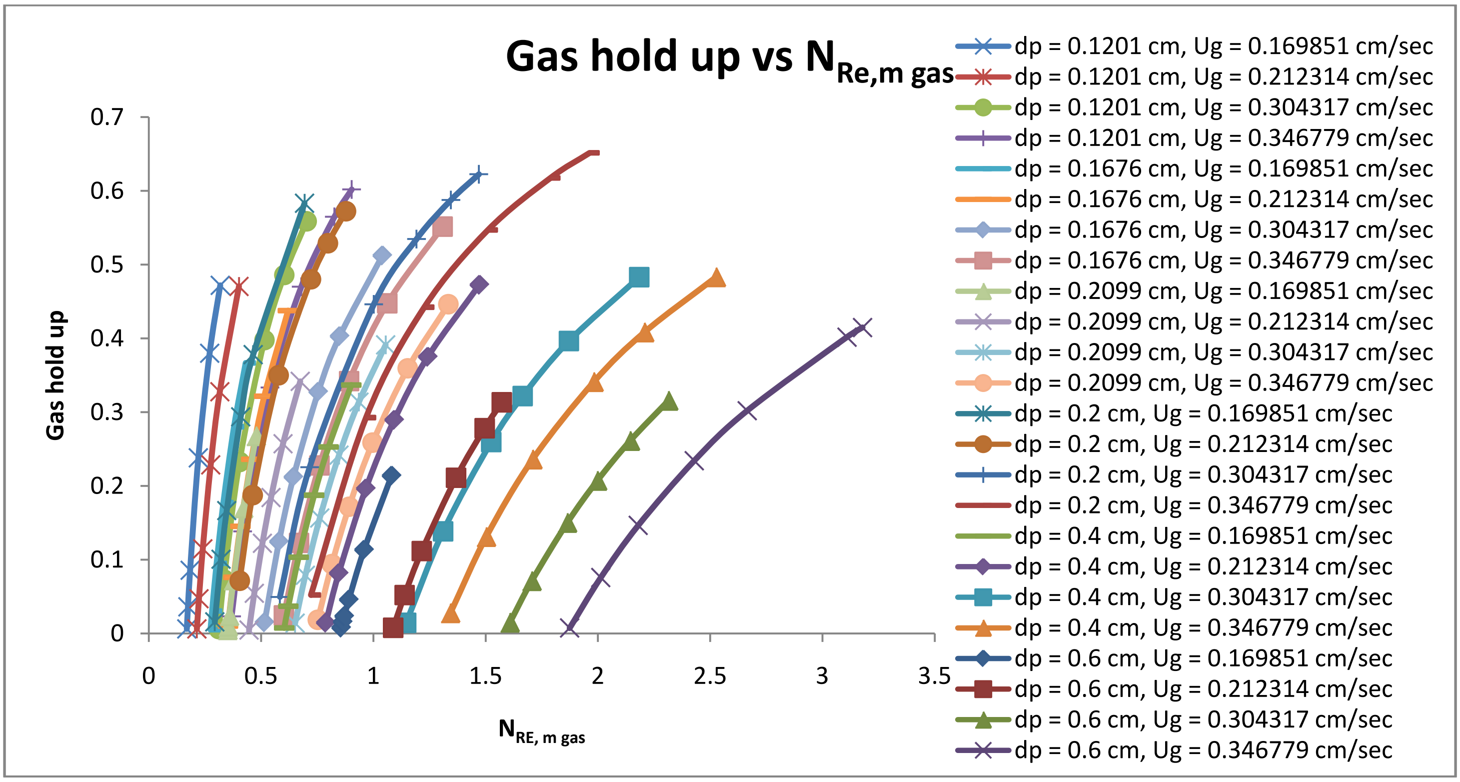

Figure 3.6 Gas holdup vs $N_{Re,\ m\ gas}$

3.4 LIQUID HOLDUP (ε_l)

It is observed that ε_l is decreasing with increasing gas phase Modified Reynolds number as well as liquid phase Modified Reynolds number and approaching a constant value at higher Modified Reynolds numbers. The gas and liquid phases are moving co-currently through the column; however the liquid phase velocities are higher than gas phase velocities obtained in this work. So, since the liquid passage through the column is faster, less liquid accumulation occurs in the column and this accumulation decreases with increase in liquid velocity; this results in reduction in liquid holdup as the liquid phase Modified Reynolds number increases.

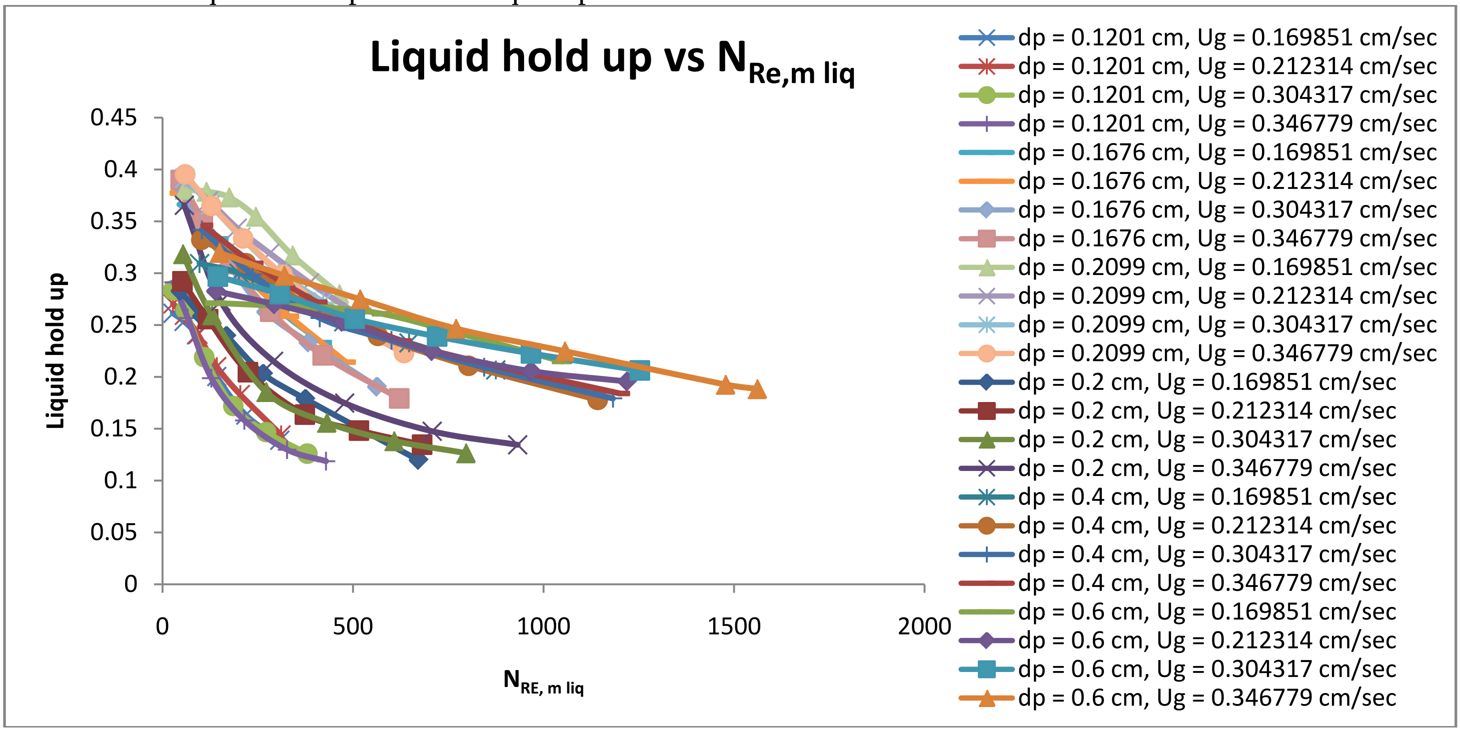

Figure 3.7 Liquid holdup vs $N_{Re,\ m\ liq}$

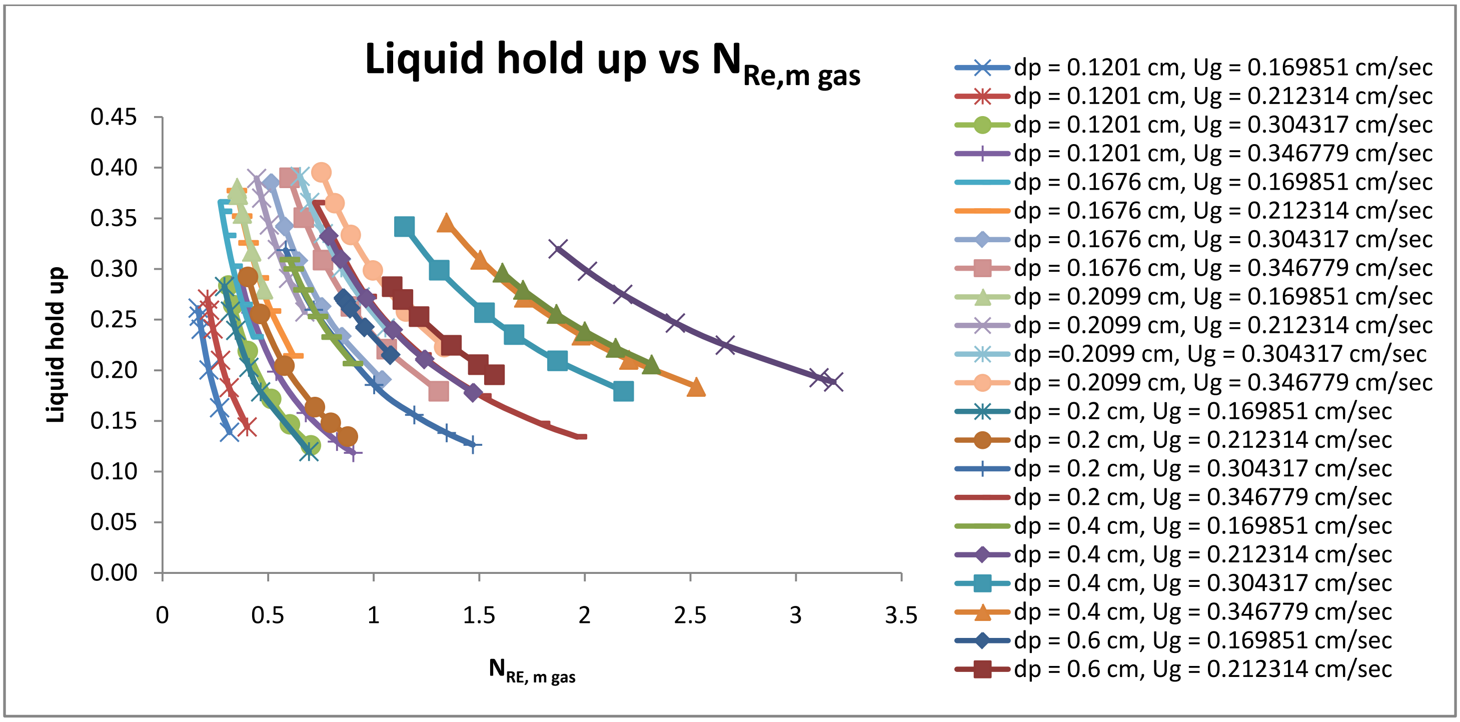

Figure 3.8 Liquid holdup vs $N_{Re,\ m\ gas}$

3.5 PRESSURE DROP (ΔP)

The results show that the pressure drop increases with increase in Modified Reynolds number (both gas and liquid). A increases is observed with lower liquid phase Modified Reynolds number whereas the increases is gradual with high liquid phase Modified Reynolds number. Pressure drop is higher for large particle sizes.

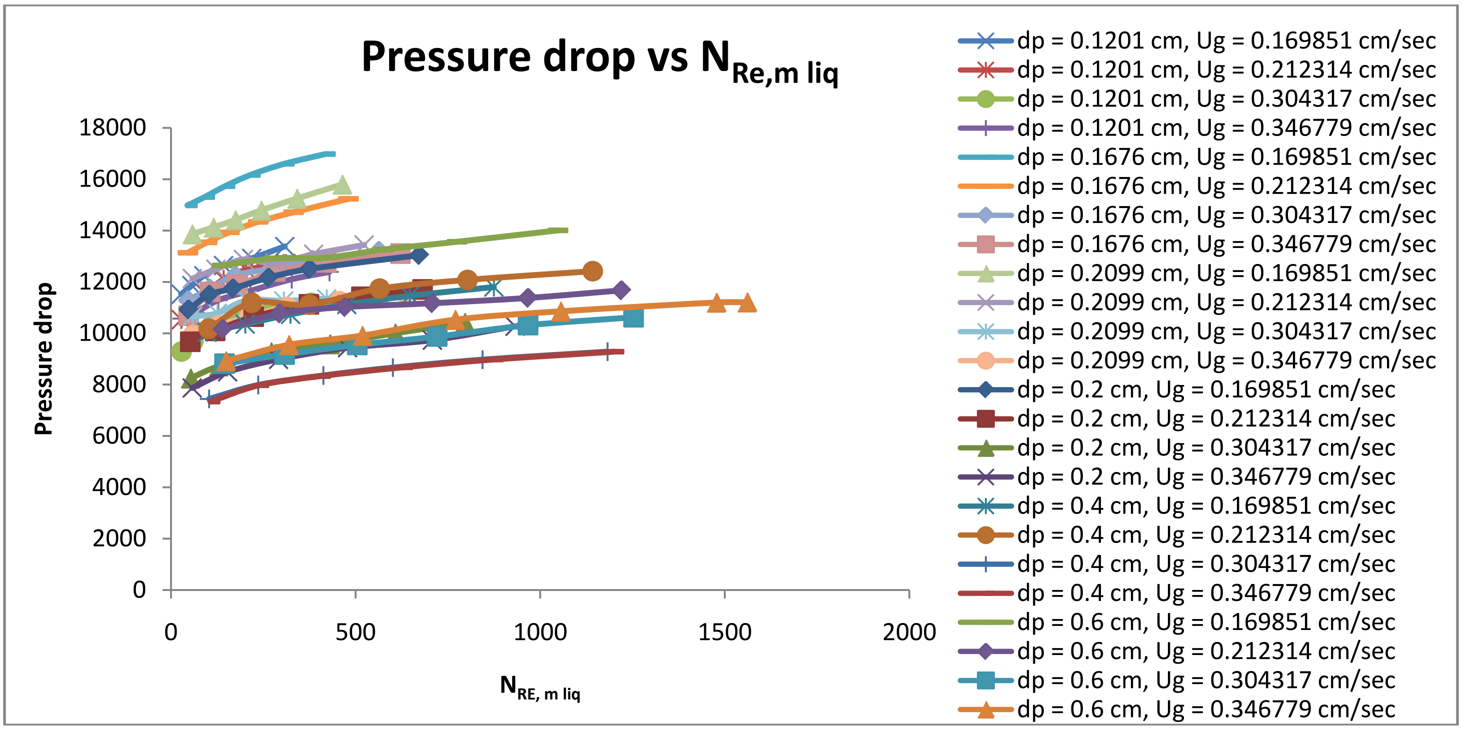

Figure 3.9 Pressure drop vs $N_{Re,m\ liq}$

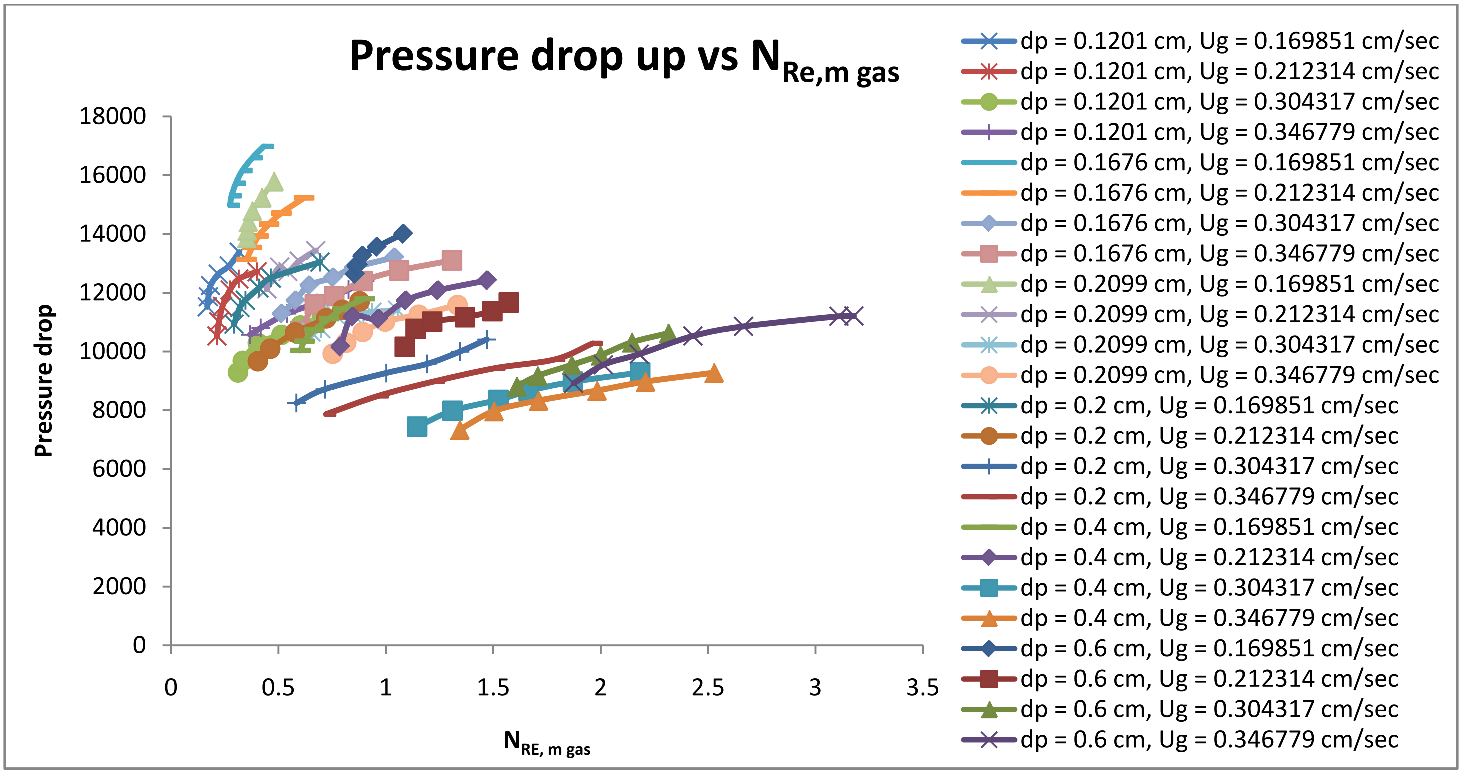

Figure 3.10 Pressure drop vs $N_{Re,\ m\ gas}$

4.0 SIMULATION

A training data set, which is required to design the optimal knowledge base of the fuzzy logic-based expert system, is collected by conducting experimental studies on hydrodynamics characteristics of cocurrent three phase fluidization (as discussed in the earlier section) using fluidized bed for different combinations of parameters.

To develop a fuzzy logic-based expert system for the above problem, four parameters, namely Eulers number, Reynolds number, particles diameter, liquid and gas flow rates are considered as inputs and gas holdup and liquid holdup as two outputs. Five linguistic terms are considered for each of the input and output variables, namely Very Low

(V_LOW), Low (LOW), Medium (MED), High (HIGH) and Very High (V_HIGH).For simplicity, the shape of the membership function distributions is assumed to be triangular. As there are five linguistic terms for element size and shape ratio each, a total of 25 (i.e., 5 · 5) rules are to be considered.

Thus, a typical rule will look as follows.

IF EU is V_HIGH AND NRE is V_LOW AND DIA is LOW AND GFR is V_LOW, THEN GHP is MED

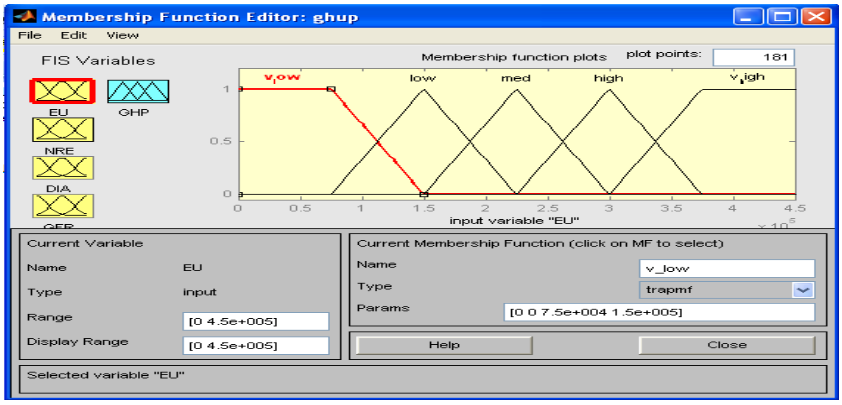

Figure4.1 Membership Function for Input Variable EU.

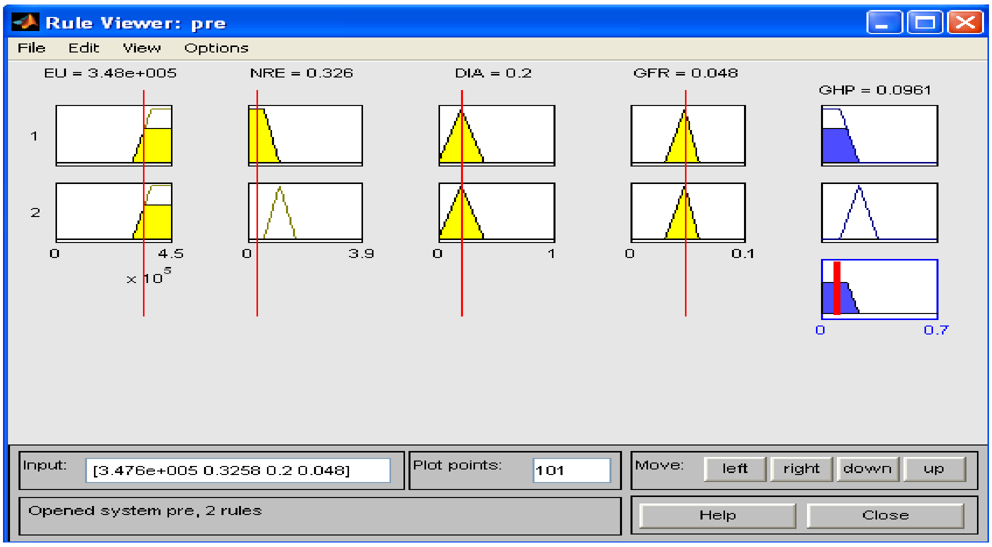

Figure 4.2 Rule Viewer During Training The Expert System.

5.0 CONCLUSION:

Improvement of mixing between liquid and solid particle in a fluidized bed can be achieved by a simple and effective method, in which gas is a mass transfer aid has been reported. Phase holdups, bed porosity and pressure drop in a gas-liquid-solid fluidized bed showed a marked variation with particle size and liquid flow rate at constant gas flow rate, bubble break-up occurs in beds at high liquid flow rate and low gas flow rate. In the break-up regime, the gaseous phase forms a uniform dispersion of small bubbles. The gas holdup is greater in smaller particle and increase with increase in gas flow rate. Bed porosity increase with increase in gas flow rate and it is high in small particle. It is found that design calculations regarding three phase fluidized beds are based on phase holdups, flow pattern of the fluid phase and extent of mixing. The system mainly depends on good contact between solid and liquid. Fuzzy logic based expert system is used to predict the phase holdups

6.0 FOR FUTURE WORK

Genetic algorithm may be used to tune fuzzy knowledge base to improve performance of the expert system.

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