Assessment of RELAP5/MOD3 Liquid Entrainment Using MSLB Experiment

Kee Soo Han and Cheol Woo Kim
KOPEC, Safety Analysis Depart., 150 Deokjin-Dong, Yuseong-Gu, Daejeon, Korea, kshan@kopec.co.kr

1. Introduction

The quantity of moisture carryover or liquid entrainment in a steam discharged through the break during a main steam line break (MSLB) accident can affect the decrease of the containment pressure and especially temperature for nuclear power plant equipment environmental qualification (EEQ) because of a lower enthalpy of the liquid relative to the steam enthalpy. Thus the liquid entrainment predicted by the analysis such as CEFLASH-4 [1] or RETRAN-3D [2] should be compared with the relevant experimental data [1,3,4] conducted by Combustion Engineering Kreisinger Development Laboratory (CE-KDL) and minimized sufficiently for conservatism.

Since there is no RELAP5 assessment for the liquid entrainment during the MSLB accident, ten experiments of the CE-KDL are analyzed by using the RELAP5/MOD3 [5] code in the present study. The analysis results of the RELAP5 are also compared with those of the CEFLASH-4 and RETRAN-3D codes.

2. Methods and Results

Figure 1 shows the CE-KDL blowdown test facility which consists of a downcomer, a centrifugal pump, inlet pipe, the steam generator region including inlet plenum and enclosure, and steam discharge piping containing blowdown valve and blowdown orifice. The enclosure contains the perforated centrifugal separator and dryer. The initial conditions of experiment and analysis are provided in Table 1. The RELAP5 nodalization for the assessment is shown on Figure 2.

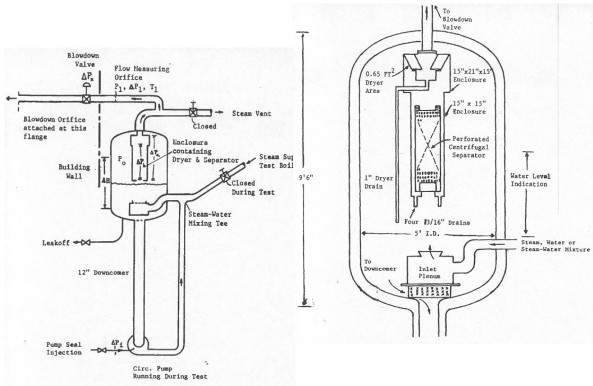


Figure 1. MSLB test loop and vessel of CE-KDL

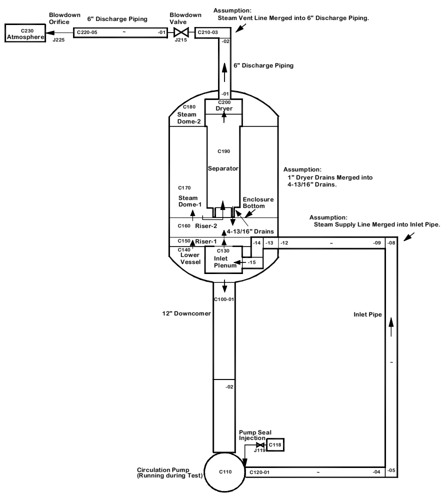


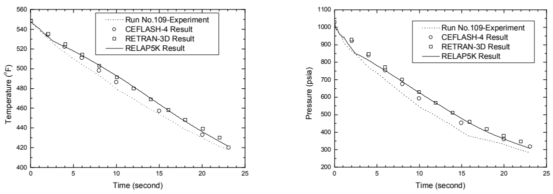
Figure 2. RELAP5 nodalization for CE-KDL test

Table 1. Summary of CE-KDL test and RELAP5 analysis results

Run No.	Run Description	L_{wi} (ft)	p_i (psia)	p_f (psia)	T_i (°F)	T_f (°F)	E_i (10^6 Btu)	E_f (10^6 Btu)	M_{wi} (lb_m)	M_{si} (lb_m)	M_{lost} (lb_m)	Run Time (sec)	E_{lost} (Btu/lb_m)	x (%)
117	Low water level,	0.749	1009.7	779.7	**545.2**	518.8	2.217	1.972	3474.0	276.3	266	9.7	921.1	58.92
	Exp. discharge area =	0.749	1009.7	780.3	545.2	517.2	2.174	1.943	3474.0	276.3	212		1087.5	83.73
118	0.022 ft^2	0.804	1009.7	694.7	**545.0**	503.6	2.193	1.859	3425.3	278.7	337	13.2	991.2	69.55
		0.804	1009.7	710.6	545.0	506.5	2.149	1.845	3425.1	278.8	276		1104.3	86.22
119		0.745	1014.7	569.7	**545.4**	**480.2**	2.221	1.714	3477.3	277.7	487	23.0	1041.1	77.07
		0.745	1014.7	567.2	545.4	481.8	2.174	1.688	3477.1	277.7	430		1137.9	91.08
114	High water level,	-0.055	1019.7	879.7	552.5	531.7	2.589	2.330	4156.7	243.9	382	9.2	678.0	21.56
	Exp. discharge area =	-0.055	1019.7	846.5	546.9	526.7	2.534	2.310	4193.4	243.2	251		893.8	54.54
115	0.022 ft^2	-0.019	1019.7	814.7	551.5	522.2	2.571	2.205	4130.6	245.6	522	13.8	701.0	24.74
		-0.019	1019.7	789.2	546.9	518.5	2.519	2.191	4161.2	244.8	376		872.3	51.57
116		-0.170	1019.7	669.7	553.5	499.7	2.641	2.069	4252.1	238.8	716	23.0	798.9	41.33
		-0.170	1019.7	701.0	546.9	504.9	2.584	2.062	4296.1	238.1	635		821.6	44.49
109	Medium water level,	0.546	1024.7	309.7	548.8	**417.2**	2.318	1.303	3638.7	271.9	1064	23.0	953.9	65.82
	Exp. discharge area =	0.546	1024.7	309.7	547.5	421.8	2.273	1.176	3646.4	271.2	1221		895.8	57.21
	0.087 ft^2													
110	High water level,	0.018	1014.7	714.7	555.7	508.0	2.560	1.930	4069.8	245.7	906	9.3	695.4	25.79
	Exp. discharge area =	0.018	1014.7	714.4	546.3	507.3	2.500	1.880	4131.5	245.1	865		716.2	28.87
111	0.087 ft^2	0.113	1019.7	559.7	556.9	479.9	2.521	1.683	3977.4	251.3	1102	13.7	759.7	36.38
		0.113	1019.7	582.9	546.9	485.1	2.461	1.617	4042.0	250.7	1135		743.5	33.86
112		0.189	994.7	344.7	551.6	**425.4**	2.470	1.362	3941.4	247.6	1334	23.0	830.6	48.11
		0.189	994.7	345.0	543.9	431.9	2.413	1.263	3989.7	247.2	1416		812.5	45.58

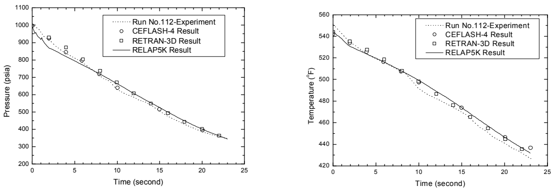
Note) L_w: water level below enclosure, p: steam pressure, T: water temperature, E: energy, M: mass, M_{lost}: total mass lost,
E_{lost}: average energy lost (= $(E_i - E_f)/M_{lost}$), x: average quality (= $(E_{lost} - h_{w,sat,pavg})/(h_{s,sat,pavg} - h_{w,sat,pavg})$), h: enthalpy,
Subscripts i: initial, f: final, w: water, s: steam, sat: saturated condition at pavg, pavg=$(p_i + p_f)/2$,
___: RELAP5 Results, **Bold**: liquid condition.

The simple separator model with separator void fraction limit of 0.2 at vapor exit junction and 0.15 at liquid fall back junction, Trapp-Ransom critical flow model with discharge coefficients of 1.0, and the choking options at only blowdown valve and orifice are used in the RELAP5 assessment.

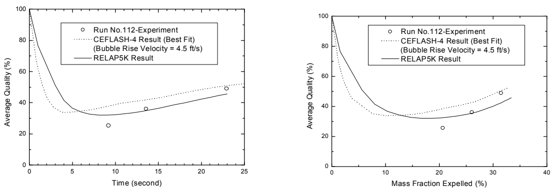


(a) Pressure (b) Temperature

Figure 3. Experimental and analytical results (Run No. 109)

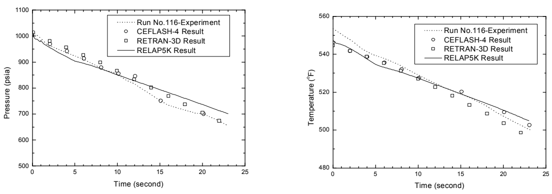


(a) Pressure (b) Temperature



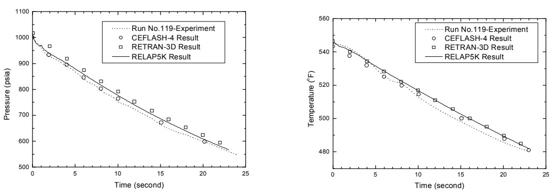
(c) Average quality (d) Break mass fraction (%)

Figure 4. Experimental and analytical results (Run No. 112)



(a) Pressure (b) Temperature

Figure 5. Experimental and analytical results (Run No. 116)



(a) Pressure (b) Temperature

Figure 6. Experimental and analytical results (Run No. 119)

Table 1 compares the summary results of the CE-KDL tests with those of the RELAP5 and Table 2 shows the standard deviation of the CE-KDL and the RELAP5 results for average quality (x) defined in Table 1. Except for test Run No. 109, 111, and 112 with larger break (discharge) area, the average quality of the RELAP5 is conservatively higher than that of the CE-KDL test as shown in Table 1 and Table 2.

Figures 3 through 6 show the pressure and temperature for test Run No. 109, 112, 116, and 119 with long test duration of 23 seconds, respectively. And Figure 4 includes time versus average quality and average quality versus mass fraction expelled (break mass fraction) for test Run No. 112. Figures show that the transient behaviors of the RELAP5 using simple separator model are in good agreement with the results of the CE-KDL tests and those of the CEFLASH-4 or the RETRAN-3D which use the bubble rise model without a separator model.

Table 2. Standard deviation of CE-KDL test results and RELAP5 analysis results for average quality.

	Average Quality (%)			
Run No.	CE-KDL Results	RELAP5 Results	CE-KDL Results / RELAP5 Results	(CE-KDL – RELAP5) Results
117	58.92	83.73	0.704	-24.81
118	69.55	86.22	0.807	-16.67
119	77.07	91.08	0.846	-14.01
114	21.56	54.54	0.395	-32.98
115	24.74	51.57	0.480	-26.83
116	41.33	44.49	0.929	-3.16
109	65.82	57.21	1.150	8.61
110	25.79	28.87	0.893	-3.08
111	36.38	33.86	1.074	2.52
112	48.11	45.58	1.056	2.53
Average Value			0.833	-10.788
Standard Deviation			0.236	13.564

3. Conclusion

In order to assess the prediction capability of the RELAP5 for liquid entrainment from the steam generator to the containment during the MSLB accident, the RELAP5 analysis is performed for 10 CE-KDL liquid entrainment experiments. The assessment results show that the average quality of the RELAP5 is conservatively higher than that of the experiment for smaller break area, while that of the RELAP5 is slightly lower or higher than that of the experiment for larger break area. From the comparison with the experiments and other analysis results, it can be concluded that the RELAP5 using simple separator model appropriately predicts the liquid entrainment behavior during the MSLB accident.

REFERENCES

[1] CENPD-80, "Moisture Carryover during an NSSS Steam Line Break Accident," January 1973

[2] D.S. Dong and Y.C. Park, "Development and Application of an Entrainment Model for the PWR U-tube Steam Generators for Main Steam Line Break Analysis," Journal of Nuclear Science and Technology, Vol.41, No.2, pp.196-206, February 2004.

[3] CENPD-80, Supplement #1, "Steam Line Break Blowdown Tests KDL Test Report," February 25, 1974.

[4] CENPD-80, Supplement #2, "Verification of Calculational Methods," February 26, 1974.

[5] The RELAP5 Development Team, "RELAP5/MOD3 Code Manual," NUREG/CR-5355, August 1995.