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Appendix I

Table of experimental results and specimen calculations

Table A-1 Experimental results from Kubota KND-3 engine:

Cooling water temperature 212 °F, atmospheric pressure 14.696 psi.

Speed rpm.	Run No.	Air temp. °F.	Exhaust temp. °F.	Orifice press. differential, in.WG.	Gas temp. °F.	Gas pressure, $lb_f/in.^2$	Air flowrate, $lb_m/min.$	Diesel fuel consumption, $lb_m/min.$	Gaseous fuel consumption, $lb_m/min.$	Total fuel consumption, $lb_m/min.$	Engine brake load, lb_f	Brake horse power, Hp.	Brake mean effective press $lb_f/in.^2$	Brake thermal efficiency %	Percent gas in total fuel.	Percent gas in air.	Hydrocarbon %	Carbon monoxide %	Carbon dioxide %	Exhaust smoke, Bosch number	Remarks
1200	1	90	290	2.40	–	–	.37267	.00527	–	.00527	1.94	0.387	15.38	16.90	–	–	–	–	2.00	0.55	
↑	2	90	311	↑	–	–		.00554	–	.00554	2.09	0.419	16.61	17.37	–	–	–	–	2.00	0.40	
	3	90	392		–	–		.00838	–	.00838	4.56	0.912	36.19	25.30	–	–	.01	0.040	3.30	1.20	
	4	90	464		–	–		.01064	–	.01064	6.25	1.250	49.58	27.00	–	–	.01	0.085	4.40	2.80	
	5	90	572	↓	–	–		.01364	–	.01364	7.75	1.550	61.47	26.12	–	–	.02	0.130	5.25	4.20	
	6	89	743	2.40	–	–	.37267	.01948	–	.01948	9.50	1.900	75.35	22.42	–	–	.03	1.020	6.10	6.10	
	7	87	790	2.35	–	–	.36833	.02207	–	.02207	10.00	2.000	79.32	20.83	–	–	.03	1.400	6.20	6.80	
	8	86	271	2.35	86	12	.37269	.00301	.00530	.00831	2.00	0.400	15.86	10.11	63.78	1.42	.10	0.290	1.90	0.00	Nozzle No.30
	9	86	338	2.35	86	↑	.37269	.00393	↑	.00923	4.00	0.800	31.73	18.36	57.42	↑	.07	0.330	2.55	0.80	
	10	88	428	2.37	88		.37307	.00617		.01147	6.00	1.200	47.59	22.51	46.21		.05	0.355	3.35	2.10	
	11	88	518	2.37	88	↓	.37270	.00870	↓	.01400	8.00	1.600	63.46	24.87	37.86	↓	.035	0.330	4.30	3.10	
	12	88	644	2.37	89	12	.37270	.01233	.00530	.01763	10.00	2.000	79.32	24.96	30.06	1.42	.02	0.350	5.50	4.20	
	13	87	270	2.35	88	15	.37207	.00244	.00590	.00834	2.19	0.437	17.35	10.91	70.74	1.58	.10	0.240	1.73	0.10	
	14	88	336	2.35	↑	↑	.37207	.00348	↑	.00938	4.00	0.800	31.73	17.93	62.90	1.58	.08	0.255	2.30	0.40	
	15	87	400	2.30			.36808	.00505		.01095	5.87	1.175	46.60	22.84	53.88	1.60	.05	0.305	2.80	2.10	
	16	88	468	2.35	↓	↓	.37207	.00734	↓	.01324	7.12	1.425	56.52	23.21	44.56	1.58	.05	0.305	3.50	3.00	
	17	86	626	2.28	88	15	.36633	.01089	.00590	.01679	10.00	2.000	79.32	26.03	35.14	1.61	.04	0.220	4.95	4.30	
	18	90	280	2.45	90	20	.37678	.00080	.00688	.00768	2.12	0.425	16.86	11.23	89.58	1.83	.10	0.485	1.60	0.00	Engine, knock
	19	90	338	2.40	↑	↑	.37245	.00253	↑	.00941	3.87	0.775	30.74	17.08	73.11	1.85	.09	0.460	2.00	0.40	" "
	20	89	444	2.40			.37265	.00561		.01249	6.75	1.350	53.54	22.97	55.08	1.85	.06	0.510	3.25	1.50	" "
	21	89	500	2.40			.37302	.00693		.01381	8.125	1.625	64.45	25.19	49.82	1.85	.06	0.410	4.20	2.65	" "
	22	89	572	2.35		↓	.37049	.00916	↓	.01604	9.50	1.900	75.36	25.60	42.89	1.84	.045	0.330	4.85	3.70	" "
	23	87	644	2.31		20	.36906	.00937	.00688	.01685	10.00	2.000	79.32	25.73	40.83	1.86	.03	0.270	5.25	3.90	" "
	24	88	662	2.35		10	.37110	.01310	.00492	.01802	↑	↑	↑	24.52	27.30	1.33	.035	0.430	5.65	4.30	
	25	88	635	2.35		13	.37110	.01151	.00551	.01702				25.77	32.37	1.48	.03	0.360	5.40	4.00	
↓	26	89	626	2.35		16	.37049	.01089	.00610	.01699				25.69	35.90	1.65	.025	0.330	5.30	3.90	
1200	27	89	600	2.35	↓	20	.37049	.00980	.00688	.01668	↓	↓	↓	25.97	41.25	1.86	.03	0.305	5.30	3.70	Engine knock

Table A-1 continued.

Speed rpm.	Run No.	Air temp. °F.	Exhaust temp. °F.	Orifice press. differential, in.WG.	Gas temp. °F.	Gas pressure, $lb_f/in.^2$	Air Flowrate, $lb_m/min.$	Diesel fuel consumption, $lb_m/min.$	Caseous fuel consumption, $lb_m/min.$	Total fuel consumption, $lb_m/min.$	Engine brake load, lb_f	Brake horse power, Hp.	Brake mean effective press $lb_f/in.^2$	Brake thermal efficiency. %	Percent gas in total fuel.	Percent gas in air.	Hydrocarbon %	Carbon monoxide %	Carbon dioxide %	Exhaust smoke Bosch number	Remarks
1200	28	89	585	2.30	90	24	.37049	.00911	.00770	.01681	10.00	2.00	79.32	25.61	45.81	2.08	.035	0.305	5.10	3.20	Engine knock
1200	29	89	582	2.40	90	28	.37049	.00842	.00850	.01692	10.00	2.00	79.32	25.29	50.24	2.29	.040	0.330	4.80	3.10	Serious knock
1200	30	86	347	2.40	–	–	.37269	.00688	–	.00688	3.25	0.65	24.79	21.72	–	–	–	0.070	2.60	1.00	
1400	31	84	282	3.50	–	–	.45136	.00625	–	.00625	1.69	0.40	13.39	14.48	–	–	–	0.010	1.89	0.50	
↑	32	84	361	3.48	–	–	.44845	.00893	–	.00893	3.69	0.86	29.25	22.15	–	–	–	0.020	2.40	1.00	
	33	84	446	3.38	–	–	.44408	.01156	–	.01156	5.62	1.312	44.62	26.10	–	–	.010	0.040	3.40	1.80	
	34	85	532	3.40	–	–	.44554	.01447	–	.01447	7.25	1.692	57.51	26.87	–	–	.010	0.040	4.10	2.40	
	35	85	665	3.35	–	–	.44190	.01847	–	.01847	8.87	2.071	70.40	25.77	–	–	.020	0.110	4.95	4.10	
	36	87	775	3.23	–	–	.43228	.02229	–	.02229	10.00	2.333	79.32	24.06	–	–	.030	0.620	5.90	5.60	
	37	89	288	3.35	90	12	.43808	.00369	.00530	.00899	2.00	0.470	15.86	11.05	58.95	1.21	.090	0.250	1.80	0.50	Nozzle No.30
	38	89	356	3.37	↑	↑	.43952	.00583	↑	.01113	4.00	0.930	31.73	17.94	47.62	1.21	.070	0.230	2.30	0.65	↑
	39	88	446	3.37			.44000	.00861		.01391	6.12	1.429	48.58	22.35	38.10	1.20	.050	0.230	3.10	1.20	
	40	88	554	3.35			.43880	.01184		.01714	8.12	1.896	64.45	24.31	30.92	1.21	.035	0.230	4.00	2.40	
	41	88	662	3.38	↓	↓	.44170	.01410	↓	.02010	9.75	2.275	77.34	25.04	26.37	1.20	.025	0.220	5.20	3.80	
	42	89	671	3.32	90	12	.43518	.01503	.00530	.02033	10.00	2.333	79.32	25.36	26.07	1.22	.020	0.240	5.40	4.00	
	43	84	290	3.35	88	15	.44190	.00383	.00585	.00968	2.25	0.525	17.85	11.04	60.43	1.33	.130	0.170	1.72	0.30	
	44	84	336	3.35	↑	↑	.44190	.00495	↑	.01080	3.50	0.817	27.76	16.09	54.17	1.32	.080	0.210	2.20	0.50	
	45	83	420	3.30			.43862	.00723		.01308	5.62	1.312	44.62	21.63	44.72	1.33	.070	0.255	2.55	1.20	
	46	83	515	3.32	↓	↓	.43971	.01006	↓	.01591	7.62	1.779	60.48	24.37	36.77	1.33	.040	0.255	3.65	1.90	
	47	86	580	3.30	88	15	.43826	.01487	.00585	.02072	10.12	2.362	80.31	25.16	28.23	1.33	.030	0.320	5.00	4.10	
	48	81	300	3.50	81	20	.43518	.00338	.00695	.01033	2.69	0.627	21.32	12.69	67.28	1.53	.100	0.330	1.85	0.40	
	49	82	331	3.35	↑	↑	.44469	.00336	↑	.01031	3.50	0.817	27.76	16.55	67.41	1.56	.090	0.320	2.10	0.40	
	50	81	395	3.40			.44731	.00561		.01256	5.31	1.240	42.14	20.97	55.33	1.55	.070	0.380	2.95	1.10	
	51	82	419	3.35			.44390	.00612		.01307	5.87	1.371	46.60	22.42	53.17	1.56	.060	0.420	3.00	1.30	
	52	82	455	3.38			.44609	.00738		.01433	7.06	1.648	56.02	24.66	48.50	1.56	.050	0.450	3.55	[illegible]	
↓	53	82	527	3.35	↓	↓	.44469	.00914	↓	.01609	8.12	1.896	64.45	25.46	43.19	1.56	.040	0.355	4.30	[illegible]	↓
1400	54	82	617	3.40	81	20	.44609	.01210	.00695	.01905	10.00	2.333	79.32	26.00	36.48	1.56	.030	0.255	5.20	2.90	Nozzle No.30

Table A-1 continued.

Speed rpm.	Run No.	Air temp. °F.	Exhaust temp. °F.	Orifice press. differential, in. WG.	Gas temp. °F.	Gas pressure, $lb_f/in.^2$	Air flowrate, $lb_m/min.$	Diesel fuel consumption, $lb_m/min.$	Gaseous fuel consumption, $lb_m/min.$	Total fuel consumption. $lb_m/min.$	Engine brake load, lb_f	Brake horse power, Hp.	Brake mean effective press. $lb_f/in.^2$	Brake thermal efficiency, %	Percent gas in total fuel.	Percent gas in air.	Hydrocarbon %	Carbon monoxide %	Carbon dioxide %	Exhaust smoke (Bosch number)	Remarks
1400	55	80	734	3.35	–	–	.44572	.02048	–	.02048	9.75	2.275	77.34	25.53	–	–	–	0.240	6.40	4.70	Nozzle No.30
↑	56	81	671		82	12	.44542	.01427	.00535	.01962	9.75	2.275	77.34	25.62	27.27	1.20	–	0.320	5.70	3.60	
	57	81	680		↑	15	.44511	.01364	.00593	.01957	9.75	2.275	77.34	25.57	30.30	1.33	.005	0.280	5.60	3.60	
	58	81	630			20	.44511	.01212	.00695	.01907	9.50	2.217	75.36	25.35	36.44	1.56	.010	0.305	5.20	3.30	↓
	59	82	600			25	.44451	.01167	.00792	.01959	9.50	2.217	75.36	24.88	40.47	1.78	.020	0.340	5.05	3.00	Engine knock
↓	60	82	575		↓	30	.44408	.01040	.00894	.01934	9.75	2.275	77.34	24.65	46.22	2.01	.025	0.390	4.80	2.85	" "
1400	61	82	552	3.35	82	34	.44390	.00955	.00974	.01929	9.50	2.217	75.36	24.57	50.49	2.19	.030	0.440	4.80	2.50	Serious knock
1800	62	84	314	6.05	–	–	.58239	.00872	–	.00872	1.37	0.412	10.91	11.46	–	–	–	0.020	1.85	0.25	
↑	63	88	325	6.05	–	–	.57528	.00739	–	.00739	1.87	0.562	14.87	17.50	–	–	–	0.020	1.95	0.10	
	64	88	419	6.00	–	–	.57312	.01197	–	.01197	3.76	1.125	29.75	21.60	–	–	–	0.020	2.90	0.40	
	65	89	518	5.85	–	–	.56592	.01576	–	.01576	5.75	1.725	45.61	25.16	–	–	.010	0.025	3.95	1.00	
	66	92	600	5.80	–	–	.56376	.01853	–	.01853	7.00	2.100	55.52	26.05	–	–	.010	0.050	4.55	1.50	
	67	90	622	5.80	–	–	.56376	.01962	–	.01962	7.75	2.325	61.47	27.24	–	–	.035	0.050	4.90	1.90	
	68	86	700	5.83	–	–	.57030	.02285	–	.02285	9.00	2.700	71.39	27.16	–	–	.040	0.085	5.40	2.55	
	69	86	797	5.80	–	–	.56885	.02645	–	.02645	10.00	3.000	79.32	26.61	–	–	.070	0.220	6.40	4.25	
	70	88	313	5.90	88	12	.57204	.00503	.00530	.01033	1.75	0.525	13.88	10.86	51.34	0.89	.060	0.205	1.80	0.00	Nozzle NO.30
	71	89	320	5.90	↑	↑	.56909	.00506	↑	.01036	2.00	0.600	15.86	12.37	51.16	0.90	.070	0.200	1.90	0.20	↑
	72	89	370	5.86			.56987	.00685		.01215	3.12	0.937	24.79	16.66	43.62	0.90	.050	0.205	2.15	0.10	
	73	89	428	5.88			.57059	.00938		.01468	4.62	1.387	36.69	20.62	36.12	0.89	.030	0.205	2.55	0.40	
	74	88	544	5.90			.57204	.01430		.01960	7.19	2.156	57.01	24.31	27.04	0.89	.025	0.220	3.80	1.40	
	75	88	605	5.83			.56697	.01573		.02103	8.00	2.400	63.46	25.29	25.20	0.90	.015	0.255	4.50	1.60	
	76	88	725	5.73		↓	.56304	.01971	↓	.02501	10.00	3.000	79.32	26.67	21.14	0.90	.005	0.200	5.20	2.70	
	77	88	305	5.80		15	.56611	.00608	.00585	.01193	1.94	0.581	15.37	10.44	49.04	1.00	.070	0.280	1.68	0.30	
	78	87	408	5.80		↑	.56791	.00809	.00590	.01399	4.00	1.200	31.73	18.63	42.17	1.00	.045	0.255	2.05	0.40	
	79	88	529	5.80			.56611	.01263	↑	.01848	6.12	1.837	48.58	21.92	31.65	1.00	.025	0.240	3.00	0.80	
↓	80	88	635	5.80			.56611	.01602		.02187	8.00	2.400	63.46	24.26	26.75	1.01	.010	0.230	4.00	1.90	
1800	81	88	716	5.70	↓	↓	.56231	.01907	↓	.02479	10.00	3.000	79.32	26.68	33.63	1.02	.005	0.230	5.15	2.60	↓

Table A-1 continued.

Speed rpm.	Run No.	Air temp. °F.	Exhaust temp. °F.	Orifice press. differential, in. WG.	Gas temp. °F.	Gas pressure, lb_f/in^2	Air flowrate, $lb_m/min.$	Diesel fuel consumption, $lb_m/min.$	Gaseous fuel consumption, $lb_m/min.$	Total fuel consumption, $lb_m/min.$	Engine brake load, lb_f	Brake horse power, Hp.	Brake mean - effective press lb_f/in^2	Brake thermal efficiency, %	Percent gas in total fuel,	Percent gas in air.	Hydrocarbon %	Carbon monoxide %	Carbon dioxide %	Exhaust smoke (Bosch number)	Remarks
1800	82	86	770	5.75	91	12	.56667	.02065	.00510	.02575	10.00	3.000	79.32	25.82	19.80	0.90	.015	0.210	6.00	3.00	Nozzle No.30
	83	87	730	5.65	↑	15	.56099	.01920	.00570	.02490	↑	↑	↑	26.57	22.89	1.02	.020	0.250	5.60	2.50	↑
	84	87	721	5.75		20	.56573	.01850	.00665	.02515				26.12	26.44	1.17	.030	0.270	5.40	2.60	
	85	86	687	5.75		25	.56667	.01649	.00764	.02413				27.00	31.66	1.35	.030	0.295	5.25	2.70	↓
↓	86	86	680	5.65	↓	30	.56231	.01553	.00860	.02413	↓	↓	↓	26.34	35.64	1.53	.030	0.305	5.15	2.50	Engine knock
1800	87	86	630	5.70	91	15	.56449	.01261	.01160	.02421	10.00	3.000	79.32	26.59	47.91	2.06	.030	0.280	5.00	2.10	Nozzle No.70
2000	88	89	305	7.30	–	–	.62727	.00708	–	.00708	0.87	0.292	6.94	9.47	–	–	.010	0.020	2.00	0.00	
	89	90	374	7.23	–	–	.62511	.00988	–	.00988	2.25	0.750	17.85	17.45	–	–	.010	0.030	2.40	0.15	
	90	90	491	7.15	–	–	.62186	.01488	–	.01488	4.50	1.500	35.69	23.17	–	–	.020	0.030	3.90	0.60	
	91	90	651	7.15	–	–	.62186	.02091	–	.02091	6.81	2.271	54.04	24.96	–	–	.020	0.030	5.05	1.55	
	92	90	721	7.10	–	–	.62006	.02397	–	.02397	8.00	2.667	63.46	25.57	–	–	.030	0.040	5.70	2.20	
	93	91	932	6.97	–	–	.61501	.02943	–	.02943	10.00	3.333	79.32	26.03	–	–	.045	0.320	7.00	4.70	
	94	89	356	7.25	92	12	.62719	.00632	.00530	.01162	2.00	0.670	15.86	12.36	45.61	0.85	.070	0.280	1.95	0	Nozzle No.30
	95	89	419	7.33	↑	↑	.62976	.00917	.00530	.01447	3.69	1.229	29.25	18.52	36.63	0.84	.050	0.270	2.35	0.40	↑
	96	89	563	7.10			.62169	.01467	↑	.01997	6.25	2.083	49.58	23.07	26.54	0.85	.030	0.280	3.50	0.80	
	97	88	662	7.05	↓	↓	.61949	.01856	↓	.02386	8.00	2.667	63.46	24.99	22.21	0.86	.020	0.280	4.40	1.40	
	98	88	806	7.00	92	12	.61893	.02458	.00530	.02988	10.00	3.333	79.32	24.96	17.74	0.86	.010	0.280	5.30	3.10	
	99	88	347	7.05	91	15	.62038	.00723	.00590	.01313	2.00	0.667	15.86	10.95	44.93	0.95	.070	0.210	1.75	0.10	
	100	88	433	7.15	↑	↑	.62400	.01088	↑	.01678	4.00	1.333	31.73	17.36	35.16	0.05	.050	0.195	2.25	0.40	
	101	88	509	7.08			.62183	.01368		.01958	5.37	1.792	42.63	20.13	30.13	0.95	.030	0.210	3.20	0.50	
	102	88	657	7.05	↓	↓	.62038	.01861	↓	.02451	8.00	2.667	63.46	24.15	24.07	0.95	.015	0.220	4.25	1.20	
	103	88	793	6.92	91	15	.61531	.02300	.00590	.02890	9.94	3.312	78.83	25.57	20.41	0.96	.015	0.280	5.00	2.90	↓
	104	91	302	7.20	91	15	.62352	.00320	.01145	.01465	1.18	0.604	14.38	8.49	78.16	1.84	.130	0.470	1.70	0	Nozzle No.70
	105	91	410	7.15	↑	↑	.62136	.00624	↑	.01769	4.62	1.542	36.69	18.29	64.72	1.84	.080	0.490	2.40	0.25	↑
	106	91	482	7.10			.61920	.00879		.02024	6.06	2.021	48.09	21.22	56.57	1.86	.080	0.545	3.00	0.50	
↓	107	91	600	7.05	↓	↓	.61704	.01254	↓	.02399	8.25	2.750	65.44	24.61	47.73	1.86	.050	0.420	3.90	1.10	
2000	108	91	716	6.98	91	15	.61488	.01651	.01145	.02796	10.00	3.333	79.32	25.81	40.95	1.86	.030	0.330	4.80	2.50	↓

Table A-1 continued.

Speed rpm.	Run No.	Air temp. °F.	Exhaust temp. °F.	Orifice press. differential, in.WG.	Gas temp. °F.	Gas pressure, $lb_f/in.^2$	Air flowrate $lb_m/min.$	Diesel fuel consumption, $lb_m/min.$	Gaseous fuel consumption, $lb_m/min.$	Total fuel consumption, $lb_m/min.$	Engine brake load, lb_f	Brake horse power, Hp.	Brake mean - effective press. lb_f/in^2	Brake thermal efficiency,%	Percent gas in total fuel.	Percent gas in air.	Hydrocarbon %	Carbon monoxide %	Carbon dioxide %	Exhaust smoke (Bosch number)	Remarks
2000	109	90	302	7.30	90	25	.62797	.00149	.01550	.01699	1,50	0.500	11.90	5.96	91.23	2.49	.300	1.180	1.60	0	Nozzle No.70
↑	110	88	356	7.40	↑	↑	.63359	.00298	↑	.01848	2.50	0.833	19.83	9.22	83.87	2.45	.200	0.850	1.80	0.10	Engine knock
	111	88	399	7.40			.63359	.00392		.01949	4.50	1.550	35.69	15.82	79.89	2.46	.100	0.700	2.50	0.20	" "
	112	88	469	7.30			.62997	.00496		.02053	6.40	2.125	50.57	21.39	75.84	2.47	.060	0.690	2.95	0.40	" "
	113	88	540	7.20	↓	↓	.62635	.00713	↓	.02262	7.87	2.625	62.47	24.21	68.49	2.47	.080	0.480	3.50	0.60	" "
	114	88	637	7.20	90	25	.62600	.01150	.01550	.02700	9.87	3.292	78.33	25.83	57.41	2.48	.085	0.410	4.50	1.40	" "
	115	86	869	7.30	-	-	.63350	.02931	-	.02931	10.00	3.333	79.32	26.14	-	-	.040	0.220	6.50	4.30	
	116	86	842	7.05	90	12	.62364	.02419	.00530	.02949	↑	↑	↑	25.31	17.97	0.85	.005	0.240	5.90	3.30	Nozzle No.30
	117	86	788	7.10	↑	15	.62522	.02320	.00590	.02910				25.56	20.27	0.94	.010	0.205	5.70	2.40	
	118	86	780	7.10		20	.62479	.02218	.00688	.02906				25.47	23.67	1.10	.030	0.220	5.75	2.50	
	119	86	770	7.05		25	.62364	.02153	.00788	.02941				25.05	26.79	1.26	.030	0.255	5.70	2.70	
	120	86	738	7.28		15	.63205	.01730	.01150	.02880				25.11	39.93	1.82	.030	0.350	5.70	2.30	Nozzle No.70
	121	86	662	7.00		18	.62218	.01491	.01270	.02761				25.98	45.99	2.04	.060	0.295	5.30	2.10	Engine knock
↓	122	86	680	7.20	↓	20	.62842	.01414	.01345	.02759	↓	↓	↓	25.90	48.75	2.14	.070	0.360	5.50	2.10	" "
2000	123	86	653	7.20	90	25	.62842	.01150	.01550	.02700	10.00	3.333	79.32	26.15	57.41	2.48	.090	0.320	5.50	1.40	" "

Table A-2 Experimental results from Petter AV-2 engine:
Cooling water temperature 160°F, atmospheric pressure 14.696 psi.

Speed rpm.	Run No.	Air temp. °F.	Exhaust temp. °F.	Orifice press. differential, in. WG.	Gas temp. °F.	Gas pressure lb_f/in^2	Air flowrate $lb_m/min.$	Diesel fuel consumption, $lb_m/min.$	Gaseous fuel consumption, $lb_m/min.$	Total fuel consumption, $lb_m/min.$	Engie brake load, lb_f	Brake horse power, Hp.	Brake mean - effective press. lb_f/in^2	Brake thermal efficiency, %	Percent gas in total fuel.	Percent gas in air.	Hydrocarbon %	Carbon monoxide %	Carbon dioxide %	Exhaust smoke (Bosch number)	Remarks
1550	1	89	432	4.05	–	–	1.8977	.03048	–	.03048	6.84	2.122	16.06	14.31	–	–	.005	.030	2.85	0	
1535	2	90	460	3.97	–	–	1.8736	.03864	–	.03864	11.00	3.377	25.82	20.09	–	–	.005	.030	3.10	0	
1515	3	90	560	3.75	–	–	1.8213	.04967	–	.04967	18.50	5.605	43.42	25.94	–	–	.005	.030	3.60	0.20	
1500	4	94	690	3.60	–	–	1.7746	.06197	–	.06197	25.31	7.594	59.41	28.17	–	–	.020	.040	4.50	1.70	
1500	5	94	780	3.46	–	–	1.7380	.07099	–	.07099	29.75	8.925	69.82	28.90	–	–	.025	.110	5.05	2.80	
1500	6	97	898	3.35	–	–	1.7013	.08112	–	.08112	33.37	10.012	78.33	28.37	–	–	.025	.220	5.50	4.95	
1480	7	99	970	3.23	–	–	1.6640	.08882	–	.08882	36.00	10.656	84.49	27.58	–	–	.030	.580	5.80	5.50	
1550	8	94	455	4.00	92	30	1.8706	.02446	.01752	.04198	6.69	2.073	15.70	10.69	41.73	.937	.065	.220	2.65	0	Nozzle No.70
1530	9	93	482	3.90	↑	↑	1.8483	.02905	↑	.04657	10.87	3.328	25.52	15.56	37.62	.948	.050	.150	2.95	0	↑
1520	10	93	555	3.75			1.8107	.03855		.05607	18.37	5.586	43.13	21.89	31.25	.968	.050	.180	3.35	0	
1500	11	93	680	3.58			1.7632	.04858		.06610	25.06	7.519	58.82	25.16	26.50	.994	.050	.180	3.80	1.50	
1500	12	96	778	3.53			1.7499	.05644		.07396	29.50	8.850	69.24	26.57	23.69	1.001	.043	.220	4.95	2.40	
1500	13	97	885	3.40	↓	↓	1.7128	.06705	↓	.08457	33.37	10.012	78.33	26.40	20.72	1.023	.030	.200	5.25	3.60	
1500	14	99	950	3.30	92	30	1.6836	.07431	.01752	.09165	36.25	10.875	85.08	26.52	19.12	1.041	.025	.280	5.55	4.75	↓
1500	15	95	498	4.10	94	30,30	1.8759	.01856	.03825	.05675	7.62	2.394	17.90	8.82	67.40	2.039	.100	.220	2.60	0.	Nozzle No.
1550	16	96	535	3.90	↑	↑	1.8421	.02174	↑	.05999	11.00	3.454	25.82	12.09	63.67	2.067	.100	.270	2.90	0	70 &45,
1550	17	96	595	3.80			1.8156	.02659		.06484	16.25	5.037	38.14	16.42	58.99	2.107	.100	.270	3.30	0	↑
1535	18	98	660	3.75			1.7960	.03154		.06979	21.00	6.447	49.29	19.64	54.80	2.130	.080	.380	3.60	0.60	
1500	19	100	770	3.60			1.7540	.04139		.07964	28.50	8.550	66.90	23.04	48.02	2.181	.050	.305	4.25	2.10	
1480	20	99	860	3.48	↓	↓	1.7272	.04801	↓	.08626	33.00	9.768	77.45	24.42	44.34	2.214	.050	.330	4.85	3.00	
1500	21	99	915	3.48	94	30,30	1.7272	.05374	.03825	.09199	36.00	10.800	84.49	25.42	41.58	2.210	.045	.380	5.20	3.95	
1480	22	99	948	3.38	–	–	1.7123	.08507	–	.08507	33.25	9.975	78.04	26.95	–	–	.025	.280	5.45	5.45	↓
1500	23	99	915	3.45	93	15	1.7210	.07942	.00590	.08532	↑	↑	↑	26.60	6.91	0.343	.015	.230	5.20	4.80	Nozzle No.30
1500	24	101	910	3.30	92	25	1.6983	.07650	.00785	.08435				26.81	9.31	0.462	.015	.240	5.15	5.00	
1500	25	97	895	3.40	90	15	1.7135	.07371	.01140	.08511				26.41	13.39	0.668	.030	.240	5.15	4.50	Nozzle No.70
1500	26	95	875	3.40	90	20	1.7200	.07003	.01348	.08351	↓	↓	↓	26.81	16.14	0.784	.025	.200	5.35	3.90	↓
1500	27	97	863	3.40	90	25	1.7135	.06695	.01550	.08245	33.25	9.975	78.04	27.06	18.80	0.905	.025	.480	5.25	3.70	

Table A-2 continued.

Speed rpm.	Run No.	Air temp. °F.	Exhaust temp. °F.	Orifice press. differential, in.WG.	Gas temp. °F.	Gas pressure lb_f/in^2	Air flowrate lb_m/min.	Diese 1 fuel consumption, lb_m/min.	Gaseous fuel consumption, lb_m/min.	Total fuel consumption, lb_m/min.	Engine brake lo ad, lb_f	Brake horse power, Hp.	Brake mean - effective press. lb_f/in^2	Brake thermal efficirncy, %	Percent gas in total fuel.	Percent gas in air.	Hydrocarbon %	Carbon monoxide %	Carbon dioxide %	Exhaust smoke (Bosch number)	Remarks
1500	28	98	875	3.45	90	30	1.7244	.06549	.01760	.08309	33.25	9.975	78.04	26.76	21.18	1.021	.025	.230	5.15	3.50	Nozzle No.70
	29	99	853	3.40	94	30	1.7063	.06020	.02075	.08095	33.25	9.975	78.04	27.19	25.63	1.216	.030	.300	5.00	3.45	Nozzle No.45
	30	98	865	3.44	92	15,20	1.7219	.05639	.02750	.08389	33.25	9.975	78.04	26.07	32.78	1.597	.035	410	4.90	3.30	Nozzle No.-
	31	99	865	3.45	92	30,20	1.7210	.05297	.03365	.08662	33.25	9.975	78.04	25.03	38.85	1.955	.050	.380	4.75	3.50	70 & 45
	32	99	850	3.50	94	28,29	1.7322	.04815	.03690	.08505	33.31	9.994	78.18	25.41	43.39	2.130	.040	.420	4.75	2.85	Engine knock
	33	99	855	3.54	94	35,35	1.7411	.04423	.04265	.08688	33.37	10.012	78.18	24.65	49.09	2.450	.040	.520	4.80	1.40	" "
	34	99	842	3.54	94	38,38	1.7420	.04185	.04510	.08695	33.37	10.012	78.33	25.88	51.87	2.589	.040	.520	4.60	1.40	" "
1500	35	102	925	3.30	-	-	1.6730	.08364	-	.08364	33.25	9.975	78.04	24.41	-	-	.020	.220	5.45	5.10	

Sample of calculation

For Kubota KND 3 engine; Bore×Stroke = 2.68×2.95 in.

Available data

Heating value of diesel oil, q_f	= 18445	Btu/lb_m
Heating value of gas, q_g	= 21180	Btu/lb_m
Engine speed, N	= 2000	rpm.
Engine brake load, W	= 10.0	lb_f
Air pressure	= 14.691	lb_f/in^2
Air temperature	= 88	°F
Orifice differential pressure	= 7.00	in.H_2O
Diesel oil consumption, m_f	=.02458	lb_m/min.
Gas pressure	= 12	lb_f/in^2
Gas temperature	= 91	°F

Air flow rate; From Fig.B-3 at 7.00 in.H_2O = 8.55 ft^3/min.

Air density at 88°F, 14.691 lb_f/in^2 = .07239 lb_m/ft^3

Air mass flow rate = 8.55×.07239 = .61893 lb_m/min.

Gas flow rate; $P_o/\sqrt{T_o} = 26.7/\sqrt{551} = 1.137$ From Fig.B-4

Gas flow rate, m_g = 0.0053 lb_m/min.

Percent gas in air $= \frac{0.0053\times100}{0.61893} = 0.896$ %

Total fuel consumption = 0.02458 + 0.0053 = 0.02988 lb_m/min.

Percent gas in total fuel by weight $= \frac{0.0053\times100}{0.02988} = 17.74$ %

Brake horse power $= WN/6000 = \frac{10 \times 2000}{6000} = 3.333$ hp.

Brake mean effective pressure, Bmep $= \frac{Bhp \times 33000}{L \times A \times n}$

where L = Engine stroke in ft. $= 2.95/12 = 0.2458$

A = Piston area in square inches $= \frac{\pi (2.68)^2}{4} = 5.641$

n = Number of power cycle per min., for four-stroke single cylinder engine = N/2

$$\text{Bmep} = \frac{3.333 \times 33000}{0.2458 \times 5.641 \times 1000}$$

$$= 79.32 \quad lb_f/in^2$$

Brake thermal efficiency $= \frac{Bhp \times 42.4 \times 100}{m_f q_f + m_g q_g}$

$$= \frac{3.333 \times 42.4 \times 100}{0.02458 \times 18445 + 0.0053 \times 21180}$$

$$= 24.96 \quad \%$$

For Petter AV 2 engine ; Bore × Stroke = 3.13 × 4.33 in.

Orifice diameter = 0.996 in., Coefficient of discharge = 0.6 .

Available data : Run No. 30

Engine speed, N	=	1500	rpm
Engine brake load, W	=	33.25	lb_f
Air pressure	=	14.691	lb_f/in^2
Air temperature	=	98	°F
Gas pressure(nozzle no.70 &45)	=	15 & 20	lb_f/in^2
Orifice pressure different, h_w	=	3.44	$in.H_2O$
Diesel oil consumption, m_f	=	0.05639	$lb_m/min.$

Air mass flow rate, $m_a = 13.0517\,\rho_a\sqrt{h_w}$ $lb_m/min.$

where ρ_a = Air density, for 98 F and air pressure 14.691 lb_f/in

= 0.07113 lb_m/ft^3

$\therefore \dot{m}_a = 13.0517 \times 0.07113\sqrt{3.44} = 1.72186$ $lb_m/min.$

Gas flow rate;

For nozzle no.70, $P_o/\sqrt{T_o} = 29.7/\sqrt{552} = 1.264$, from Fig.B-4

gas flow rate = 0.01140 $lb_m/min.$

For nozzle no.45, $P_o/\sqrt{T_o} = 34.7/\sqrt{552} = 1.447$, from Fig.B-4

gas flow rate = 0.01610 $lb_m/min.$

Total gas flow rate, m_g = 0.01140+0.01610 = 0.02750 $lb_m/min.$

Percent gas in air $= \dfrac{0.02750\ 100}{1.72186} = 1.597$ %

Total fuel consumption = 0.05639+0.02750 = 0.08389 $lb_m/min.$

Percent gas in total fuel $= \dfrac{0.02750 \times 100}{0.08389} = 32.78$ %

Brake horse power = WN/6000 = $\frac{33.25 \times 1500}{5000}$ = 9.975 hp.

Brake mean effective pressure, Bmep = $\frac{Bhp \times 33000}{L \times A \times N}$

where L = Engine stroke in ft. = 4.33/12 = 0.3608

A = Piston area in in^2 = $\frac{\pi}{4}(3.13)^2$ = 7.695

n = Number of power cycle per min., = 1500

∴ Bmep = $\frac{9.975 \times 33000}{0.3608 \times 7.695 \times 1500}$

= 78.04 lb_f/in^2

Brake thermal efficiency = $\frac{Bhp \times 42.4 \times 100}{m_f q_f + m_g q_g}$

= $\frac{9.975 \times 42.4 \times 100}{0.05639 \times 18445 + 0.0275 \times 21180}$

= 26.07 %

Appendix II

Air and gas flow measurements

B-1 Air flow measurement by an orifice

Of the many forms of airmeter available, it has been found that the orifice meter is the most satisfactory because it is cheap and easy to construct.

An orifice flow equation, which may be found in many fluid flow measurement literatures, is derived from the two principle equations, namely, the continuity and energy equations. The expression of the flowrate may be obtained as follow.

$$Q = \frac{CA_o}{\sqrt{1 - (D_o/D_1)^4}} \sqrt{2g_c(P_1/\gamma + Z_1 - P_2/\gamma - Z_2)} \qquad \text{(B-1)}$$

where
- Q = Volume rate of flow.
- C = Flow coefficient.
- A_o = Area of the orifice.
- D_o = Diameter of the orifice.
- D_1 = Diameter of pipe.
- P_1 = Upstream pressure.
- P_2 = Downstream pressure.
- Z_1 = Upstream elevation.
- Z_2 = Downstream elevation.
- γ = Specific weight.
- g_c = Accelerating gravity.

For a given meter the dimensions are known and constant. Although C varies with the rate of flow, the variation is very small, the equation (B-1) for particular meter reduced to

$$Q = K\sqrt{P_1/\gamma + Z_1 - P_2/\gamma - Z_2} \qquad \text{...(B-2)}$$

where K = constant.

It is convenient to express the term $(P_1/\gamma + Z_1)$ - $(P_2/\gamma + Z_2)$ as $H_1 - H_2$ or ΔH, the difference in head. Hence equation (B-2) becomes

$$Q = K\sqrt{\Delta H} \qquad \text{...(B-3)}$$

It is therefore concluded that the volume flow rate varies directly as the square root of the difference in head.

B-1.1 Air flow calibration

The arrangement of the apparatus used for calibrating the orifice meter was shown in Fig.B-1. A Parkinson Cowan Standard gas meter was used for calibration of flow rate which claims to be accurate within 10 in. water gauge pressure. The standard gas meter was connected to the orifice which was fitted to surge tank in order to protect pulsations from the engine suction,by a flexible pipe. The other side of surge tank was connected to the suction side of a motor pump between which a gate valve was fitted for controlling air flow. The flow rate was measured in cubic foot per minute by recording the total time required for one or more revolutions of the meter pointer with a stopwatch. The differential pressure between the orifice was also recorded in in.H_2O by a U-tube manometer. The orifice was calibrated step by step from no flow upto about 9 cubic foot per minute. Correlation between volume flow rate and the differential pressure are presented graphically in Fig.B-3.

B-2 Gas flow measurements by a choked nozzle

In this investigation a choked nozzle was used because of its advantage of being independent of downstream pressure disturbances once choking is effected. In addition it is suitable for operation requiring very small amount of gas.

The derivation of the critical flow equation based on the inlet stagnation state may be found in most thermodynamics and fluid mechanicstextbooks. By using the continuity, energy and state equations for an isentropic steady flow expansion of an ideal gas with a negligible approach velocity when flowing through a nozzle of the right geometry, the following expression is obtained.

$$\dot{m} = \frac{AP_o}{\sqrt{RT_o}} \sqrt{\frac{2g_cM\gamma}{(\gamma - 1)} \left(\frac{P_1}{P_o}\right)^{\frac{2}{\gamma}} \left\{ 1 - \left(\frac{P_1}{P_o}\right)^{\left(\frac{\gamma - 1}{2}\right)} \right\}} \qquad \text{(B-4)}$$

where $\dot{m}$ = Mass flow rate through nozzle, lb_m/min.

P_o = Absolute upstream pressure.

P_1 = Absolute throat static pressure of the nozzle.

T_1 = Absolute upstream temperature.

γ = Ratio of specific heats, C_p/C_v.

R = Universal gas constant.

A = Cross sectional area of the throat.

M = Molecular weight of the gas metered.

g_c = Acceleration due to gravity.

For critical flow conditions, i.e. sonic condition at the throat, the following condition is required:-

$$P_1/P_o = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma+1}} \qquad \text{...(B-5)}$$

For choked conditions, substituting P_1/P_o into eq.(B-4) the mass discharge rate can be expressed as

$$\dot{m} = \frac{AP_o}{\sqrt{RT_o}}\sqrt{\frac{2g_cM\gamma}{(\gamma+1)}} \cdot \left(\frac{2}{\gamma+1}\right)^{\left(\frac{1}{\gamma-1}\right)} \qquad \text{...(B-6)}$$

For a real flow a coefficient of discharge, C, is introduced into eq. (B-6) will be written as

$$\dot{m} = \frac{CAP_o}{\sqrt{RT_o}}\sqrt{\frac{2g_cM\gamma}{(\gamma+1)}} \cdot \left(\frac{2}{\gamma+1}\right)^{\left(\frac{1}{\gamma-1}\right)} \qquad \text{...(B-7)}$$

Let $\emptyset(\gamma) = \sqrt{\frac{2g_c\gamma}{(\gamma+1)}} \cdot \left(\frac{2}{\gamma+1}\right)^{\left(\frac{1}{\gamma-1}\right)}$

eq. (B-7) becomes

$$\dot{m} = \frac{CAP_o}{\sqrt{RT_o/M}} \emptyset(\gamma) \qquad \text{...(B-8)}$$

The coefficient of discharge is normally expected to be mainly dependent on the particular meter being used and the Reynold number of the flow. For a particular gas and nozzle, equation (B-8) will reduced to the following form when choked conditions are maintained:

$$m = \frac{K P_o}{\sqrt{T_o}} \qquad \text{... (B-9)}$$

From equation (B-9), it is evident that the mass flow rate is independent of the downstream pressure and varies directly as the upstream conditions. This is based on the assumption that the pressure ratio is always greater than the critical pressure ratio, equation (B-6), and there is no change in gas properties.

B-2.1 Gas flow calibration

The schematic diagram arrangement of the apparatus used for calibrating the nozzle were shown in Fig.B-2. The nozzles used in this calibration were Nissan M3 no. 70 and Zenith no. 45 carburettor jets and no. 30 which was made in the same appearance as Zenith no. 45's. These jets may be considered as convergentor convergent-parallel nozzles.

The commercial butane gas supplied in high pressure cylinders was used in the calibration test (and was burnt out after passing the standard gas meter). A regulating valve was fitted to the cylinder for adjusting the upstream gas pressure upto 50 lb_f/in^2 gauge. The coarse and fine needle valves were fitted to the pipe line for controlling the flow of gas to the nozzle. Upstream gas pressure and temperature were measured by a Bourdon tube pressure gauge and a mercury thermometer dipped into the gas circuit recorded the temperature. The downstream pressure and temperature were measured by a red oil manometer (specific weight 0.827) and a mercury thermometer. The gas was passed through a standard Parkinson Cowan gas meter mentioned previously. The flow rate was measured in litre per minute by recording the total time required for one or more revolutions of the handle of the meter. The gas flow rate was converted to pound per minute and plotted against the upstream $P_o/\sqrt{T_o}$ ratio as shown in Fig. B-4.

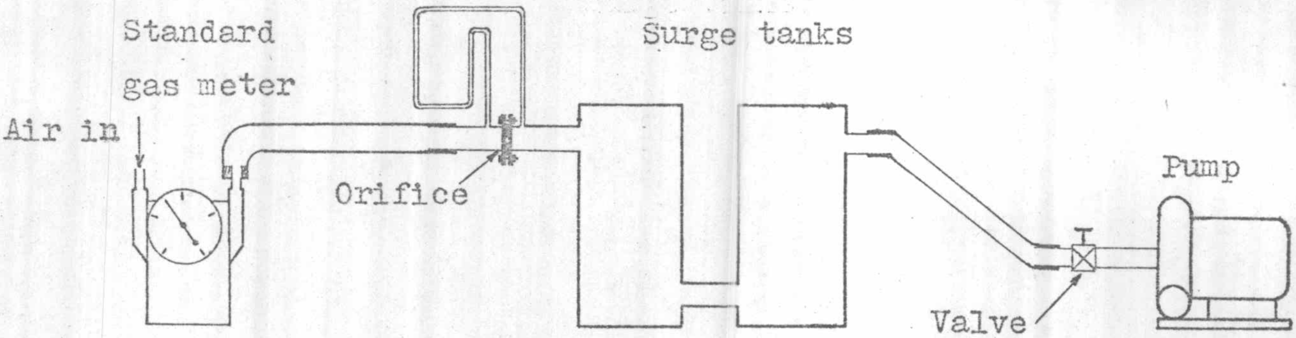

Fig.B-1 The Assembly of Apparatus for Calibrating Orifice Meter.

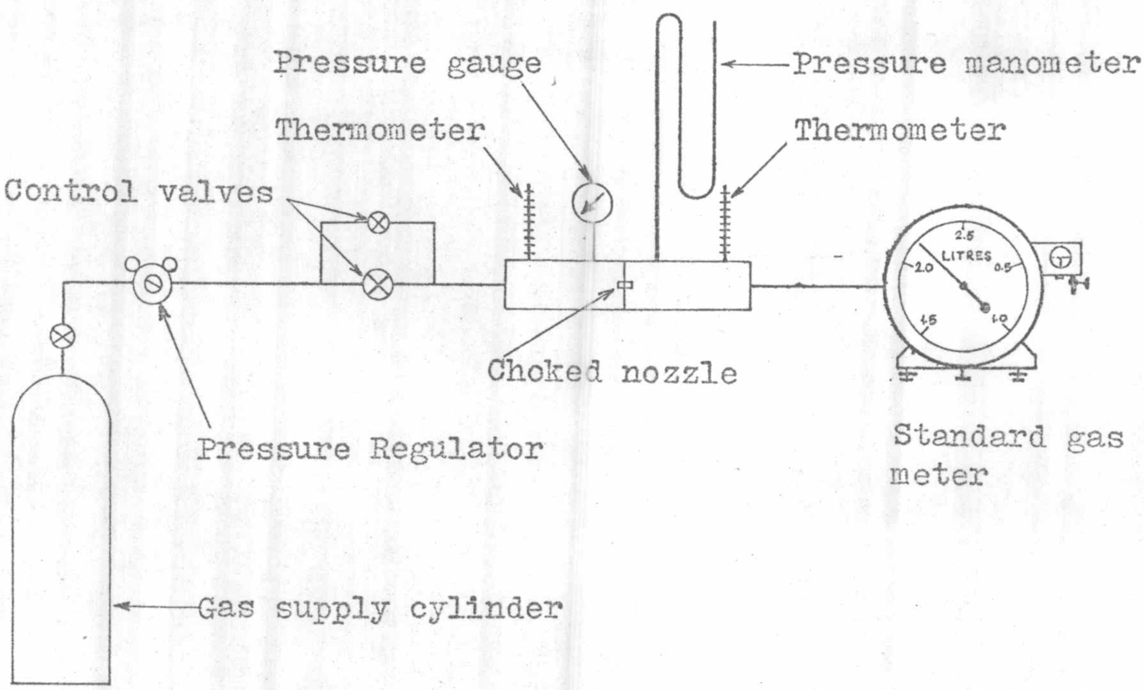

Fig.B-2 Schematic lay out of Apparatus for Calibrating Choked Nozzle Flow Meter.

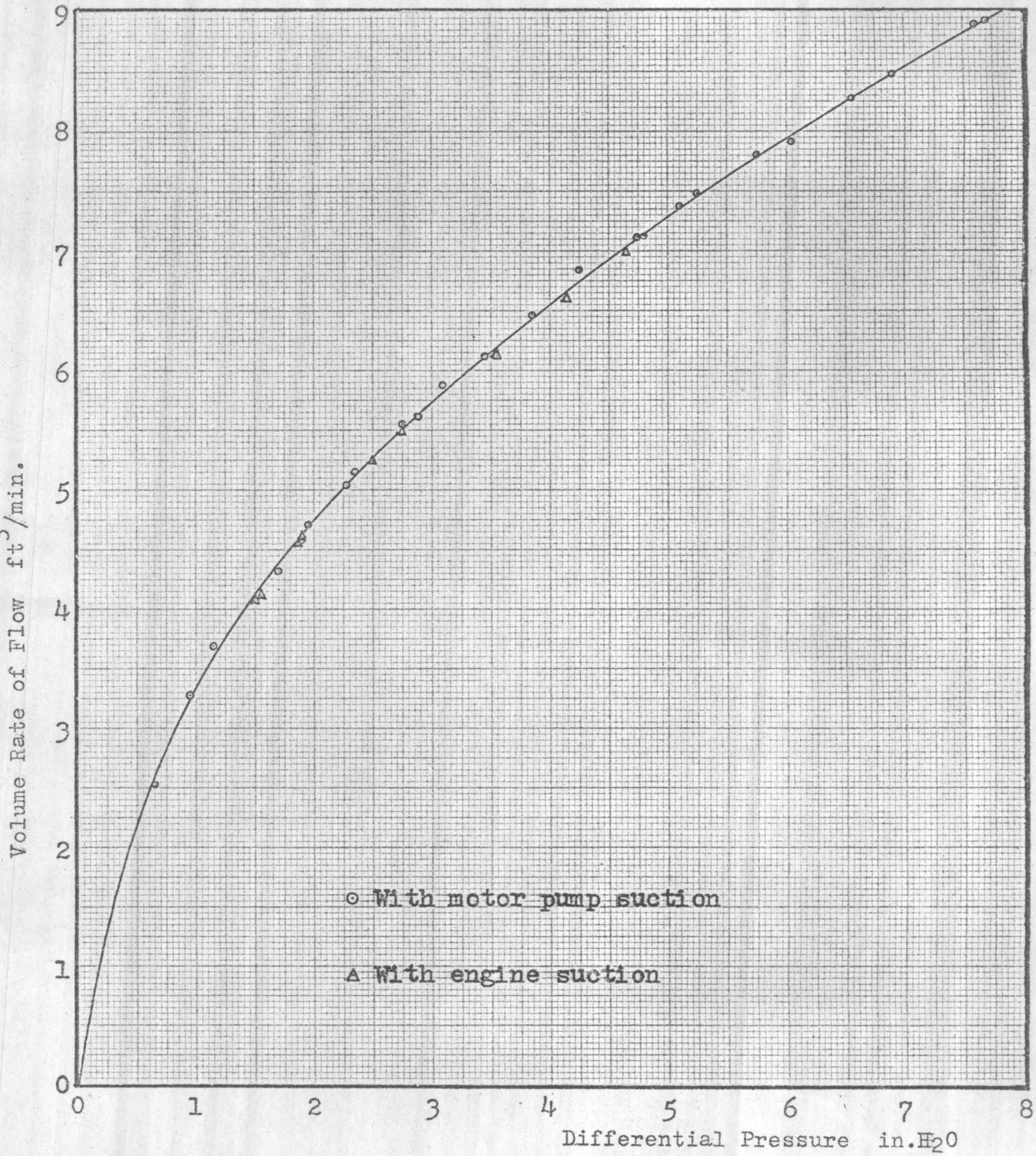

Fig.B-3 Orifice Meter Calibration Curve.

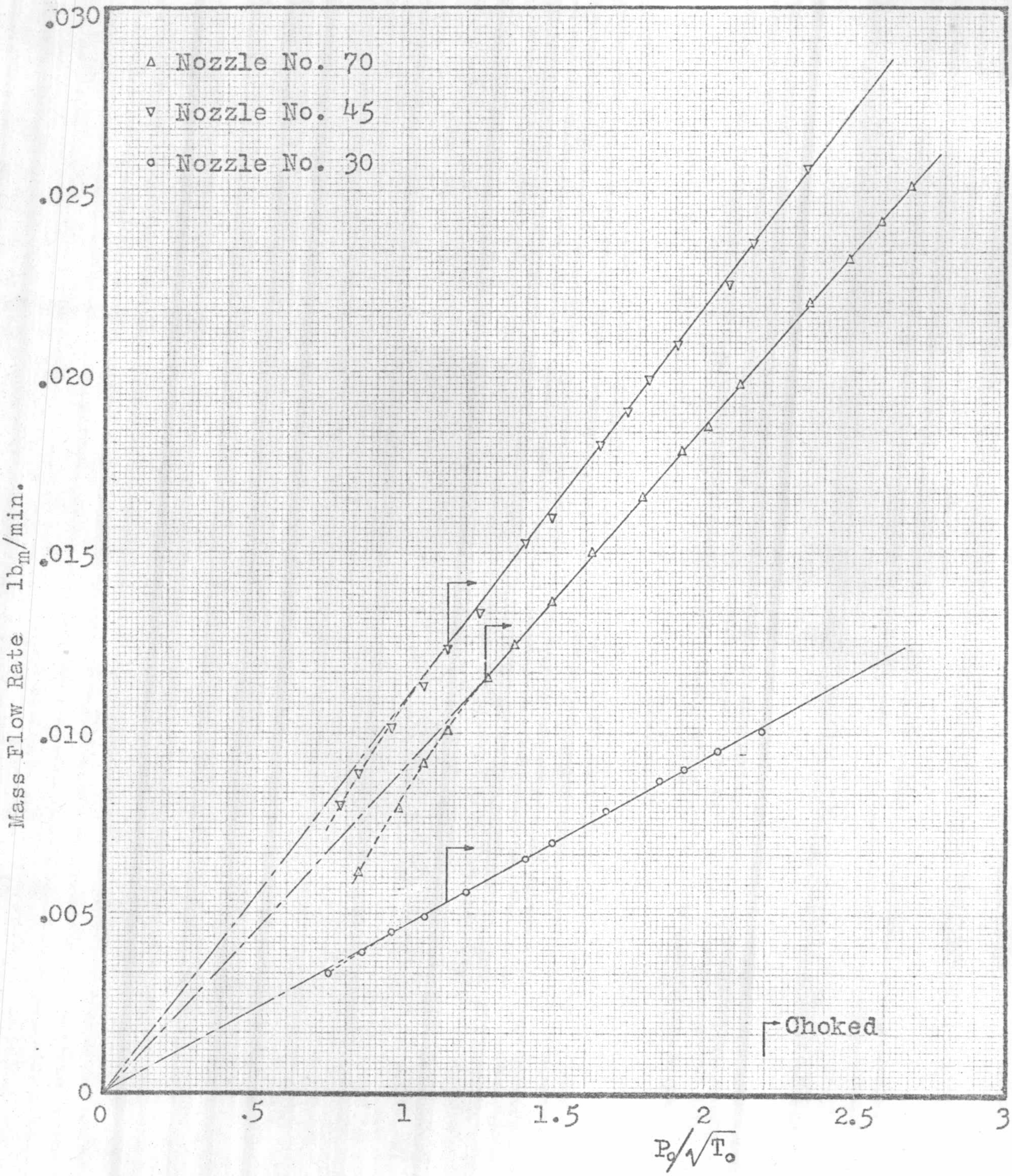

Fig.B-4 Choked Nozzle Calibration Curves.

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