Conditioned Combustion Air Improves Performance of Supercharged Diesels, Gas-Diesels and Gas Engines

improvement in load-carrying ability and specific fuel consumption.

Effects. *Fig. 1 shows typical effects* of aftercooling on a supercharged diesel. Note that besides a reduction in specific fuel consumption there is increased load-carrying ability for a given thermal load on piston, rings, valves and other parts.

If maximum allowable cylinder-outlet temperature is 800 F on engine with aftercooler, maximum permissible load is 180-psi bmep, Fig. 1. Same engine without aftercooling is limited to about 130-psi bmep. So we can say thermal load at 130-psi bmep is same as at 180-psi bmep using an aftercooler.

Aftercoolers on supercharged 4-cycle *gas-diesel and spark-ignited gas* engines have perhaps a more important function than on a diesel. It was quickly learned while developing these engines that scavenging-air temperature and quantity fix maximum load-carrying ability before reaching detonation.

These engines require an air-fuel ratio of 17 to 1 on the rich side, 30 to 1 on the lean. Controls maintain air-fuel ratio as near 17 to 1 as possible to avoid detonation. If it occurs, it indicates mixture is too rich for existing conditions. Cylinder temperature alone limits maximum load on diesel engines, whereas *detonation is the limiting factor* for gas-diesel and spark-ignited gas engines. In the latter detonation results from pre-ignition or extremely fast burning of the gas charge.

Aftercoolers. Fig. 2 shows effect of an aftercooler on a supercharged gas diesel and progress made over a 4-year period. Fuel consumption indicated for the 1946 engine was obtained on the prototype of a present-day engine.

Improvements in 1948 on gas-admission and ignition equipment produced fuel curve indicated. Curve turn-up above 120-psi bmep was, along with *detonation, the clue for need for cooler air.* Effect of an aftercooler is shown in 1950 curve. It is considerably flatter, permitting ratings to 180-psi bmep before detonation limits output.

Using detonation as limit on output, aftercooler alone permits rating increases to 30% over 1948 engines, and 56½% over 1946. Study of curves in Fig. 2 shows that detonation limit of 180-psi bmep can be raised if more effective means can be found to further reduce combustion-air temperature.

Trying larger aftercoolers shows that price and size are prohibitive. Studies and tests developed a true conditioner for combustion air. It humidifies and cools incoming air, allowing ratings to 200-psi bmep before detonation.

Fig. 3 shows 1950 fuel curve, along with 1952 curve for a unit having a conditioner. Although evaporative cooling was first used solely to reduce combustion-air temperature to increase specific output, it soon became apparent that certain other gains were made on atmospheric 2-cycle gas engines and supercharged 4-cycle gas and gas-diesel engines.

Besides increasing rating, conditioning system lowers specific fuel consumption, improves combustion characteristics by more orderly flame propagation, lowers cylinder heat load to increase life of rings, pistons, valves and other parts, and eliminates deration for high ambient temperatures.

Improving combustion is particularly significant because fuel gases with higher detonating characteristics than natural gases composed largely of methane can be burned.

Locality. Heretofore it has generally been considered that evaporative cooling equipment could be successfully used only in semi-arid climates. Analysis of wet-bulb temperatures on the Gulf coast shows they have not exceeded 84 F. This means that an evaporative cooler can cool air to 90 F anywhere in the U. S. Standard rating temperatures of the Diesel Engine Manufacturers Assn are based on an inlet-air temperature of 90 F.

Atmospheric Engine, 4-Cycle. Assume two initial conditions, one with 115-F dry-bulb (d-b), 65-F wet-bulb (w-b), the other with 100-F d-b and 84-F w-b *for inlet air.* Here's what a conditioning system will do for a 4-cycle atmospheric engine:

	Case 1	Case 2
Initial conditions	115-F d-b 65-F w-b	100-F d-b 84-F w-b
Cooling to within 5 F of w-b gives engine combustion air at	70-F d-b 75% rh*	89-F d-b 70% rh*

*Relative humidity

Case 1 represents semi-arid conditions, 2 the Gulf coast.

Fig. 4 shows system used. It is simply an evaporative cooler and humidifying unit piped to engine air inlet. Small water pump circulates water to spray nozzles in cooler. Water consumption under average conditions is 0.15 lb per hphr. This brings air temperature within 5 F of w-b temperature.

Pressure-Charged, 2-Cycle. Fig. 5 shows system for gas engines of this type, having a blower to supply scavenging air at pressures to 4.5 in. Hg. Similar to unit in Fig. 4, pump circulates 50-100 gpm through fog nozzles in the cooler. Water consumption under average conditions runs 0.3 lb per hphr. Evaporative cooler can reduce air temperature to within 7 F of ambient wb. Aftercooler on blower discharge is used to lower air temperature to within 15 F of cooling medium temperature. Latter is a variable depending on prevailing conditions.

Without conditioning, an engine with 115-F d-b and 65-F w-b air at inlet at 3000-ft elevation in a semi-arid area *receives air from blower at* 153-F db, 1% rh (approximate). With conditioning equipment, results are:

Initial conditions	115-F db 65-F wb
After evaporative cooler	72-F db 70% rh
After compressor	107-F db 29% rh
After aftercooler; combustion air supplied engine	87-F db 40% rh

Further gains are made by adapting the same basic system in a slightly different manner, bringing air through compressor and a combined *aftercooler*-evaporative cooler to air-inlet manifold, Fig. 7. This system utilizes the aftercooler more efficiently than is possible with hookup in Fig. 5. Humidifying efficiency of evaporative cooler is improved because it's used on the discharge side of compressor instead of inlet side.

With same initial conditions earlier assumed, combustion air is supplied engine as follows:

Initial conditions	115-F db 65-F wb
Air from compressor	153-F db 77-F wb
Air from aftercooler	95-F db 59-F wb
Air from evaporative cooler to engine	66-F db 66% rh

Gains. Conditioner in Fig. 7 not only lowers air temperature to a level 21 F below that in Fig. 5; it also raises it 26%—from 40 to 66%. Gain is signi-

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Table of Economical Chimney Sizes

Based on 68-F atmospheric temperature, chimney-gas specific weight 0.0772 lb per cu ft, elevation 851 ft (29.0 in. Hg) above sea level, friction coefficient 0.018

Chimney delivery, lb gas per sec	Gas temperature, 500 F — Economical chimney-gas velocity, ft per sec	Economical chimney diameter,* ft	Total dynamic draft, in. wg	Economical chimney height, in feet — Chimney gas temperature 400 F	500 F	600 F
5	17.94	2.90	.25	58	49	44
10	21.13	3.83	.30	69	59	52
15	22.86	4.50	.35	81	69	61
20	24.19	5.05	.40	92	79	70
25	25.25	5.54	.45	104	88	79
30	26.31	5.96	.50	116	98	87
35	27.11	6.34	.55	127	108	96
40	27.78	6.67	.60	139	118	105
45	28.31	7.01	.65	150	128	114
50	29.11	7.30	.70	162	137	122
55	29.64	7.59	.75	173	147	131
60	30.17	7.85	.80	185	157	140
65	30.70	8.11	.85	197	167	149
70	30.97	8.35	.90	208	177	157
75	31.50	8.58	.95	220	186	166
80	31.90	8.81	1.00	231	196	175
85	32.29	9.02	1.05	243	206	184
90	32.69	9.24	1.10	254	216	192
95	33.09	9.44	1.15	266	226	201
100	33.49	9.64	1.20	277	236	210
110	34.02	10.00	1.25	289	245	219
120	34.69	10.37	1.30	301	255	227
130	35.29	10.70	1.35	312	265	236
140	35.75	11.02	1.40	324	275	245
150	36.15	11.33	1.45	335	285	254
175	37.34	12.05	1.50	347	294	262
200	38.41	12.72	1.55	358	304	271
225	39.34	13.33	1.60	370	314	280
250	40.14	13.90	1.65	381	324	289
275	40.80	14.45	1.70	393	334	297
300	41.60	14.95	1.75	405	349	306
325	42.26	15.44	1.80	416	353	315
350	42.93	15.90	1.85	428	363	324
375	43.46	16.34	1.90	439	373	332
400	43.99	16.77	1.95	451	383	341

*This temperature has little effect on diameter over wide range.

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