Nitrogen Oxides Emissions from Fluidized Bed Combustion of Different Fuels

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NITROGEN OXIDES EMISSION FROM FLUIDIZED BED COMBUSTION OF DIFFERENT FUELS

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Introduction

The level of emissions of nitrogen oxides from fluidized bed boilers is low. This one of the advantages with fluidized bed combustion. However, the limits of the standards of emissions have been decreased to very low levels and the accurate prediction of the emissions has become necessary for the boiler manufacturers in order to give guarantees not to exceed the limits. Similarly, it is important to be able to predict how a change in fuel quality affects the emissions.

Although several fuel properties may be of significance when evaluating the emissions, the present work focuses only on the influence of the volatile content of the fuel on the emission of NO but also, in one example, on the simultaneous emission of nitrous oxide N_2O.

Background

The nitrogen oxides emitted from fluidized bed combustion originate from the fuel nitrogen, but only in the order of 10% of the fuel nitrogen is converted into NO emitted. So, the influence of the reducing properties of the fluidized bed itself, and design and operating parameters play a more important role for the variation of the NO emission than the variation in the content of nitrogen from one fuel to another. (This nitrogen content of conventional solid fuels typically lies between 1 and 2% of the combustible matter). Table 1 shows a list of influencing operating and design parameters. On the other hand, the properties of the fuels lead to an interaction between the fuel and the processes in the bed and thus, the fuel characteristics need to be considered when estimating the emission.

In order to investigate this interaction between design, operating and volatile content of the fuel, a set of fuels with widely varying content of volatiles was selected, Table 2 [1].

The boilers used in the tests are shown in Fig. 1. One of the boilers is a 16 MW stationary fluidized bed (SFB) boiler and the other is an 8 MW circulating fluidized (CFB) boiler.

Results

An example of the influence of the operating parameters on the emissions of NO and N_2O is given in Figs. 2 and 3, [1]. In these tests the bed temperature was varied, whereas the other principal influencing parameters have been kept constant. It is seen that NO increases but N_2O decreases with bed temperature. Also, the order of the fuels is different for NO and N_2O emission.

The behaviour of the NO emission from the two types of boiler is shown in Figs. 4 and 5, [2]. It is evident that the emission characteristics with respect to fuel volatile content is quite different (opposite) in SFB and CFB boilers.

In order to further support the data presented in Figs. 4 and 5, a summary of published measurements involving different fuels has been carried out [2]. The result presented in Figs. 6 and 7 show that all the sets of data have the same trend. The differences in emission level of the various sets of data can be explained in most cases as a consequence of operating parameters and size of the equipment. However, in the present comparison only the trends are considered.

Comments and discussion

The decrease of the NO emission with increasing volatile content of the fuels in the SFB boilers (Figs. 4 and 6) can be interpreted as a result of the beneficial contribution to the reduction of NO of fuel volatile nitrogen compounds mostly in the form of ammonia in the splash zone or in the lower part of the freeboard.

In the CFB boiler, on the other hand, most of the volatile nitrogen compounds are either broken down or converted to N_2 before they can participate in further NO reduction. In this case the reactions involving fuel char and reduction of NO on the surfaces of char will be the most important mechanisms for NO reduction. Since there is less char per unit of boiler power with high volatile fuels, the NO emission increases with increasing volatile content. Variations in the reaction properties of the char may be the reason why the relationship found between the NO emission and volatile content in the CFB goes through a minimum (Figs. 5 and 7). In addition, the formation of NO from the nitrogen contained in the char is not yet well understood.

A further contribution to the complexity of NO reduction is the possible catalytic activity of some fuel ashes. A careful analysis of chars and bed materials indicate that it is necessary to investigate the specific chars and bed materials in laboratory tests, because the activity of char cannot be predicted from the specific surface area, and the activity of bed materials depend very much on their composition [12].

Conclusion

The emission of NO from FB boilers depends largely on design and operation parameters. However, the content of fuel volatiles do play a role which can be qualitatively described. Until more kinetic data for all the different materials in the bed and catalytic reactions are available a thorough kinetic investigation in the laboratory is necessary before quantative modelling of the fuel nitrogen in a given fluidized bed combustor is possible. A step in this direction has been taken [12, 13].

References

[1] Åmand, L.E. and Leckner, B., The influence of fuel volatiles on the emission of nitric and nitrous oxides from an 8 MW fluidized bed boiler (to be published).

[2] Åmand, L.E. and Leckner, B., The role of fuel volatiles for the emission of nitrogen oxides from fluidized bed boilers - a comparison between designs, to be presented at the 23rd (Int) Symposium on Combustion, 1990.

[3] Hampartsoumian, E. and Gibbs, B.M., J. of the Institute of Energy 57, 402 (1984).

[4] Furusawa, T., Ishikawa, S., Sudo, S. and Kunii, D., J. Chem.Engn.Japan. 16, 76 (1983).

[5] Wittler, W., Schütte, K., Rotzell, G., and Schügerl, K., Chem.Ing.Tech. 60, 420 (1988).

[6] Asai, M. and Shimoda, H., 1st Korean-Japanese Symposium on Fluidization, Seoul, 1988.

[7] Asai, M., Aoki, K., Oda, Y. and Shimoda, H., 2nd SCEJ Symposium on Fluidized Beds, p.101, Chemical Engineers of Japan, Tokyo, 1988.

[8] Suzuki, T., Ishizuka, H., Hyvarinen, K., Morita, A., Yano, K. and Hirose, R., 2nd SCEJ Symposium on Fluidized Beds, p.109, Chemical Engineers of Japan, Tokyo, 1988.

[9] Shimuzu, R. and Furusawa, T., 3rd SCEJ Symposium on Fluidized Beds, p.134. Chemical Engineering of Japan, Tokyo, 1989.

[10] Lee, Y.Y. and Hiltunen, M., Joint Symposium on Stationary Combustion NO_x Control, EPRI/EPA, San Francisco, 1989.

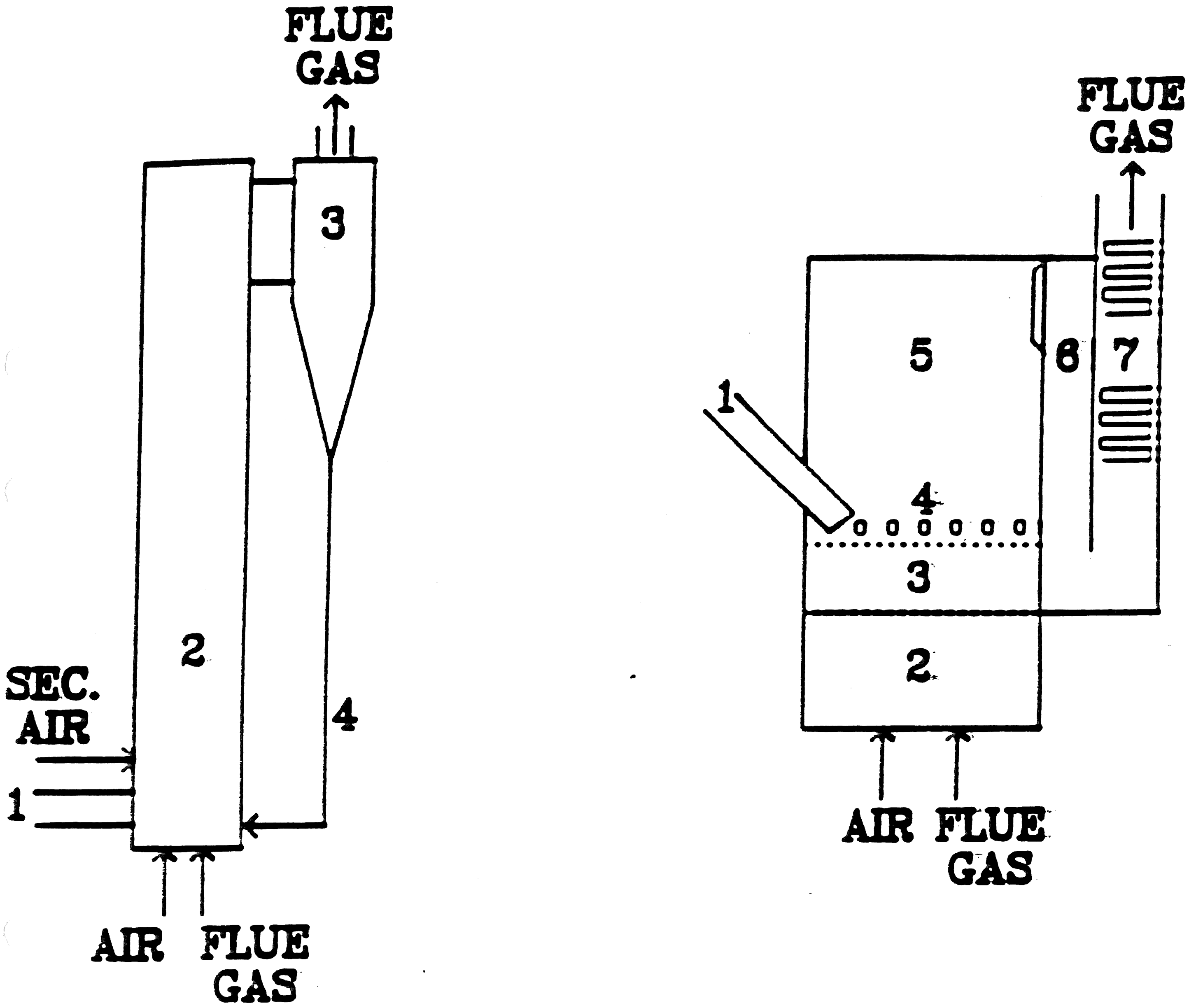
[11] Legros, R., Brereton, C.M.H., Lim, C.J., Li, H., Grace, J.R. and Anthony, E.J. 10th International Conference on Fluidized Bed Combustion, (A.M. Manaker, Ed.), Vol.2, p.661, ASME Book No 10290A, 1989.

[12] Johnsson, J.E., Kinetics of heterogeneous NO_x reactions at FBC conditions, Dept. of Chem. Eng., Tecn. Univ. of Denmark, CHEC Report No. 9003, March 1990.

[13] Johnsson. J.E., Åmand L.E. and Leckner, B., Modelling of NO_x emissions from a CFB boiler, to be presented at the 3rd Int. Conf. on CFB, Nagoya, October, 1990.

Table 1. Parameters influencing the NO emission.
(P Primary, S Secondary, D Design)

No	Type	Name
1	P	Bed temperature (bottom)
2	P	Total excess air ratio
3	P	Primary air stoichiometry
4	S	Primary air ratio (from No 3)
5	P	Fluidizing velocity a) Load b) Flue gas recirculation
6	P,S	Sort of bed material and size
7	P	Fixed carbon content in fuel
8	S	Char content bed
9	S	CO concentration in combustion chamber
10	S	Temperature distribution in combustion chamber and cyclone
11	S	Density at the top of the combustion chamber
12	D	Height of combustion chamber
13	D	Design of the combustion chamber (bottom and outlet to cyclone)
14	D	Location and design of secondary air nozzles
15	D	Cyclone efficiency and recycling rate from cyclone



a) Cityvarvet b) Chalmers

Figure 1 Schematic picture of the boilers

a) Cityvarvet. 1 – Fuel feed screw, 2 – Combustion chamber with fluidized bed, 3 – Cyclone, 4 – Particle return leg

b) Chalmers. 1 – Fuel feed chute, 2 – Air plenum, 3 – Fluidized bed, 4 – Secondary air nozzles, 5 – Freeboard, 6 – Empty gas pass, 7 – Convection gas pass

Table 2. Fuel characteristics.

Type	Wood chips[a]	Peat[b]	Brown coal	Bitu-minous coal	Petro-leum coke	Anth-racite[a]
Size, mm, mass mean	—	see text	—	6.5	7	1.9
% < 1 mm	0	10	0	11	14	50
Volatiles, % maf	86.0	72	53.1	35.5	14.3	11.1
Prox.anal, % as delivered:						
Combustibles	64.7	48.6	80	87	91	74.0
Ash	0.04	3.2	5	7	2	6.4
Moisture	35.3	48.2	15	6	7	19.6
Ultimate anal., % maf: C	51.1	56.3	67.5	82.7	89.8	92.1
H	6.3	4.6	4.9	5.2	4.1	1.6
O	42.3	36.5	25.9	8.8	2.7	2.6
S	0.03	0.5	0.8	1.6	2.0	2.3
N	0.3	2.0	0.9	1.7	1.4	1.4
Heating value, lower, MJ/kg maf	18.8	21.8	25.7	33.1	35.4	32.0

[a] CFB (Cityvarvet only) [b] SFB (Chalmers only)

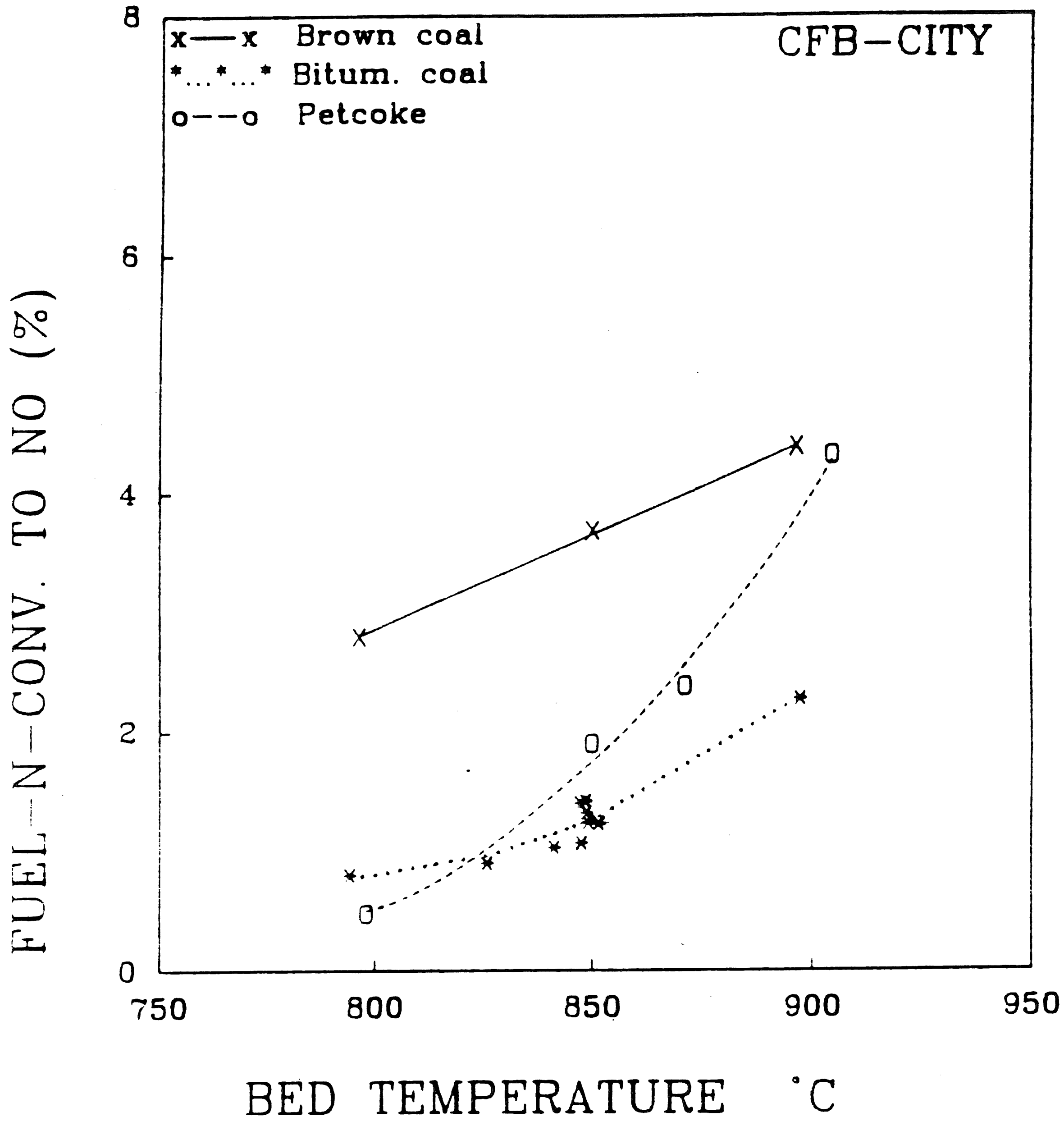


Fig. 2. Fuel nitrogen conversion to NO in the CFB boiler versus bed temperature. Primary air stoichiometry 0.7 and the excess air ratio 1.2.

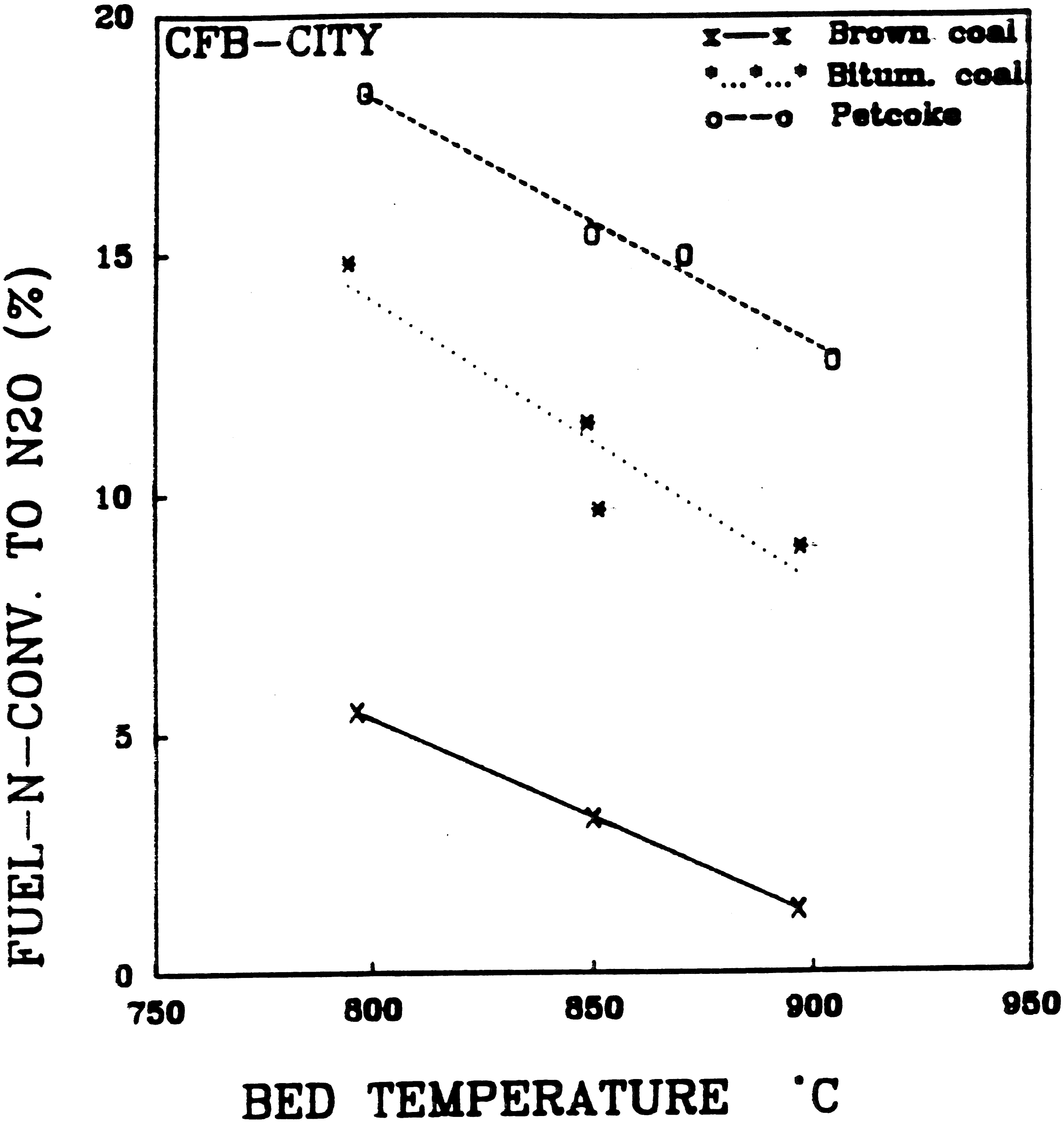


Fig. 3. Fuel nitrogen conversion to N_2O in the CFB boiler versus bed temperature. Same data as in Fig. 2.

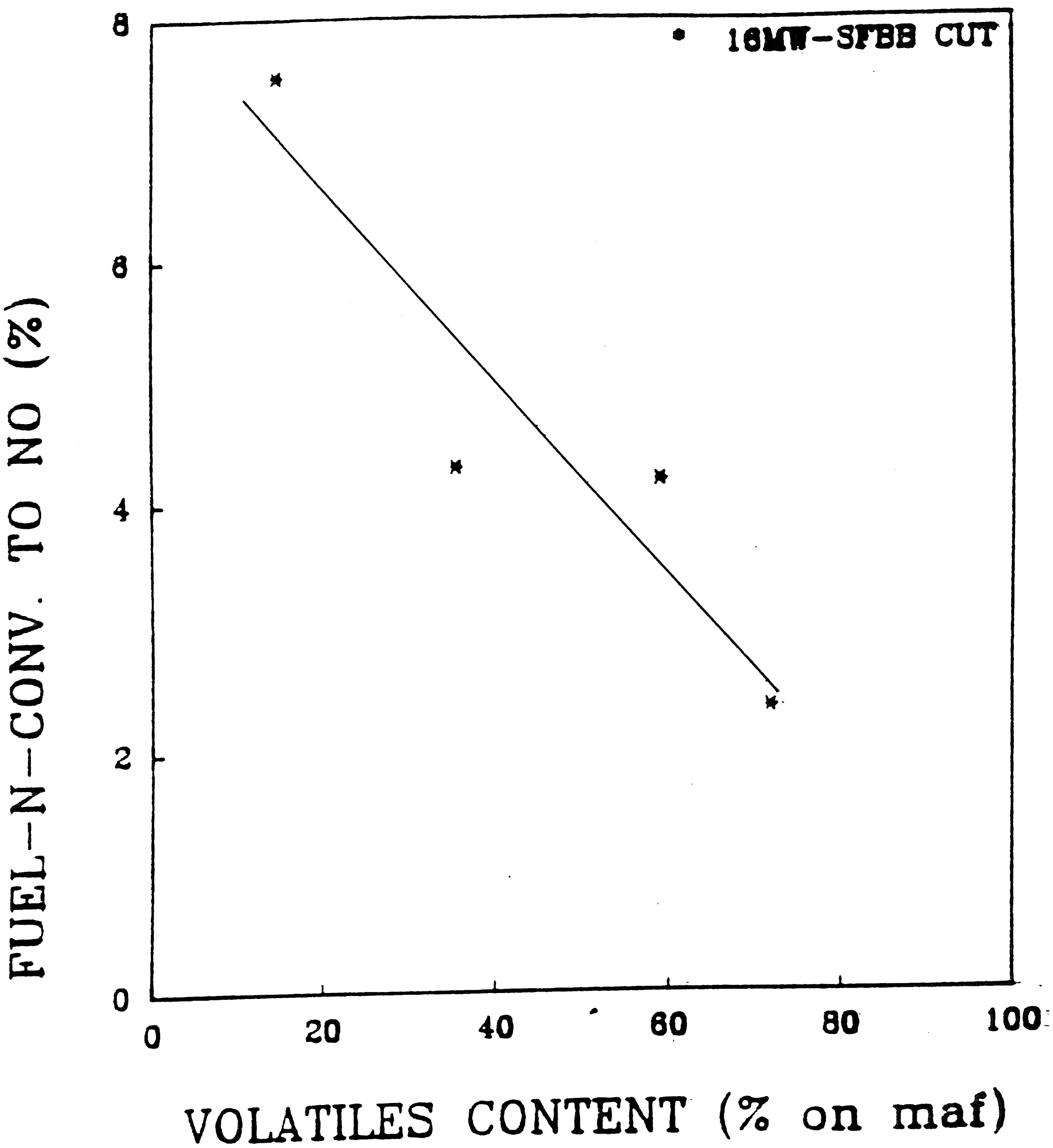


Fig. 4. Fuel nitrogen conversion to NO versus fuel volatile content during combustion in the SFB boiler.

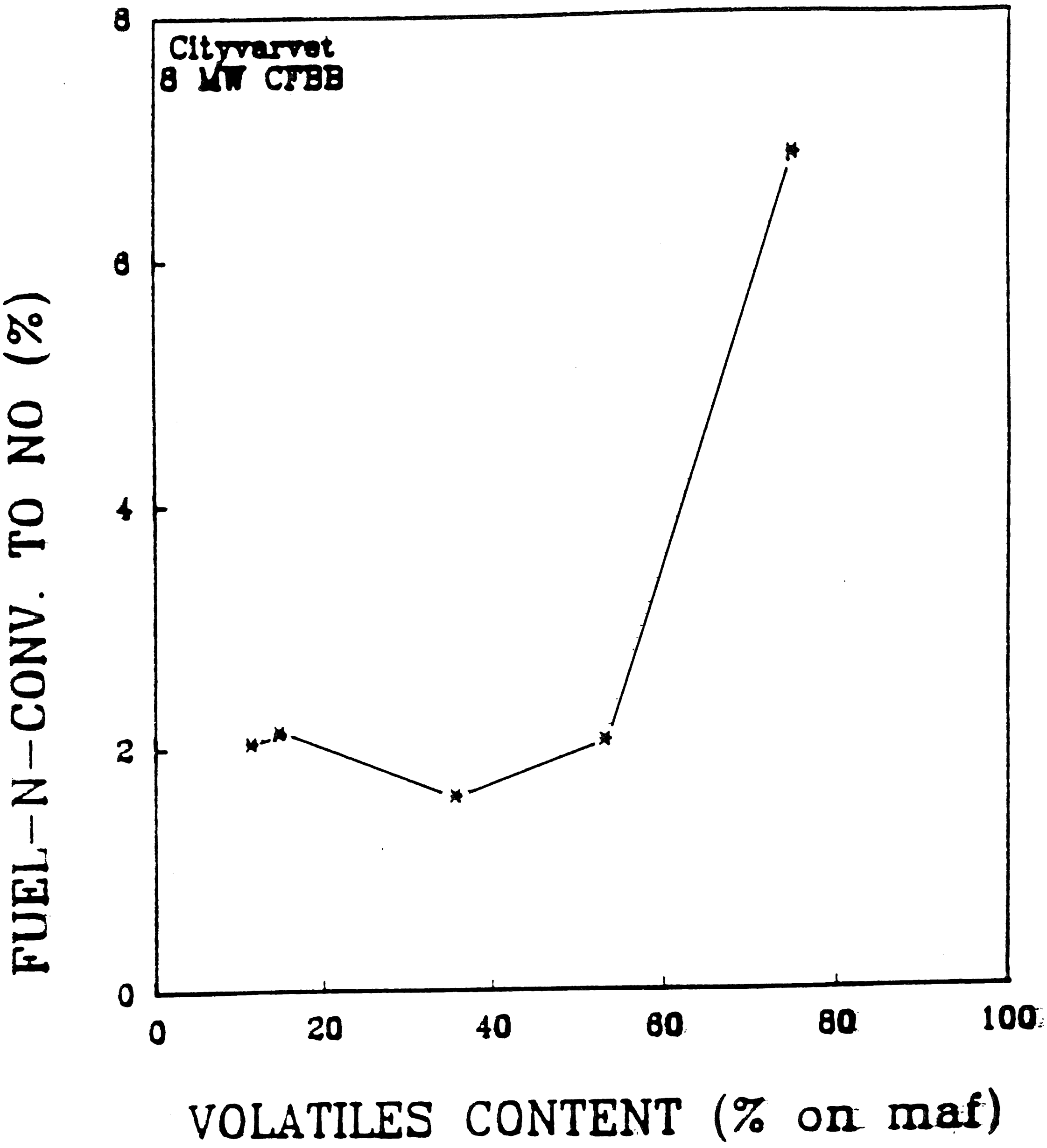


Fig. 5. Fuel nitrogen conversion to NO versus fuel volatile content during combustion in the CFB boiler.

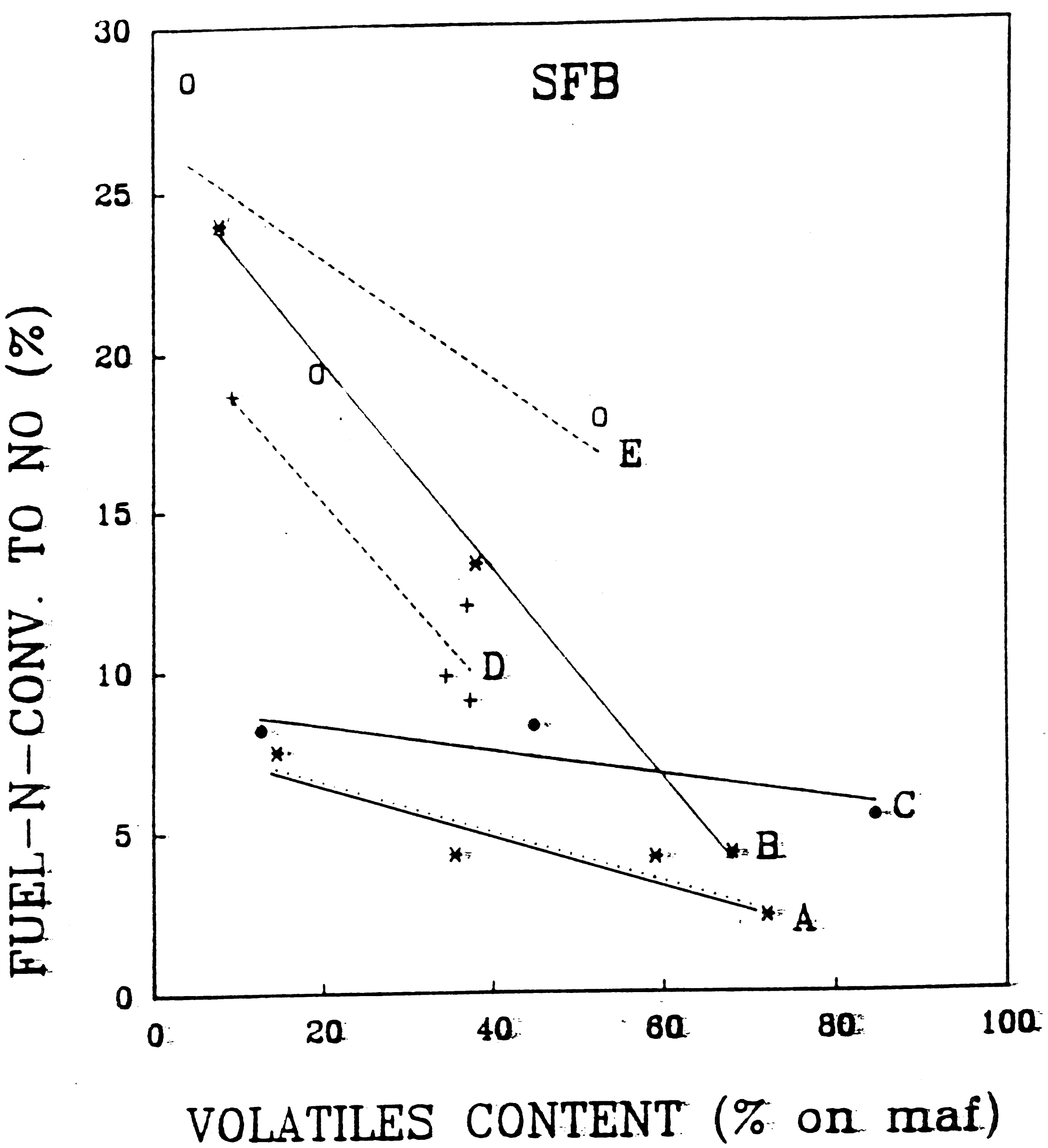
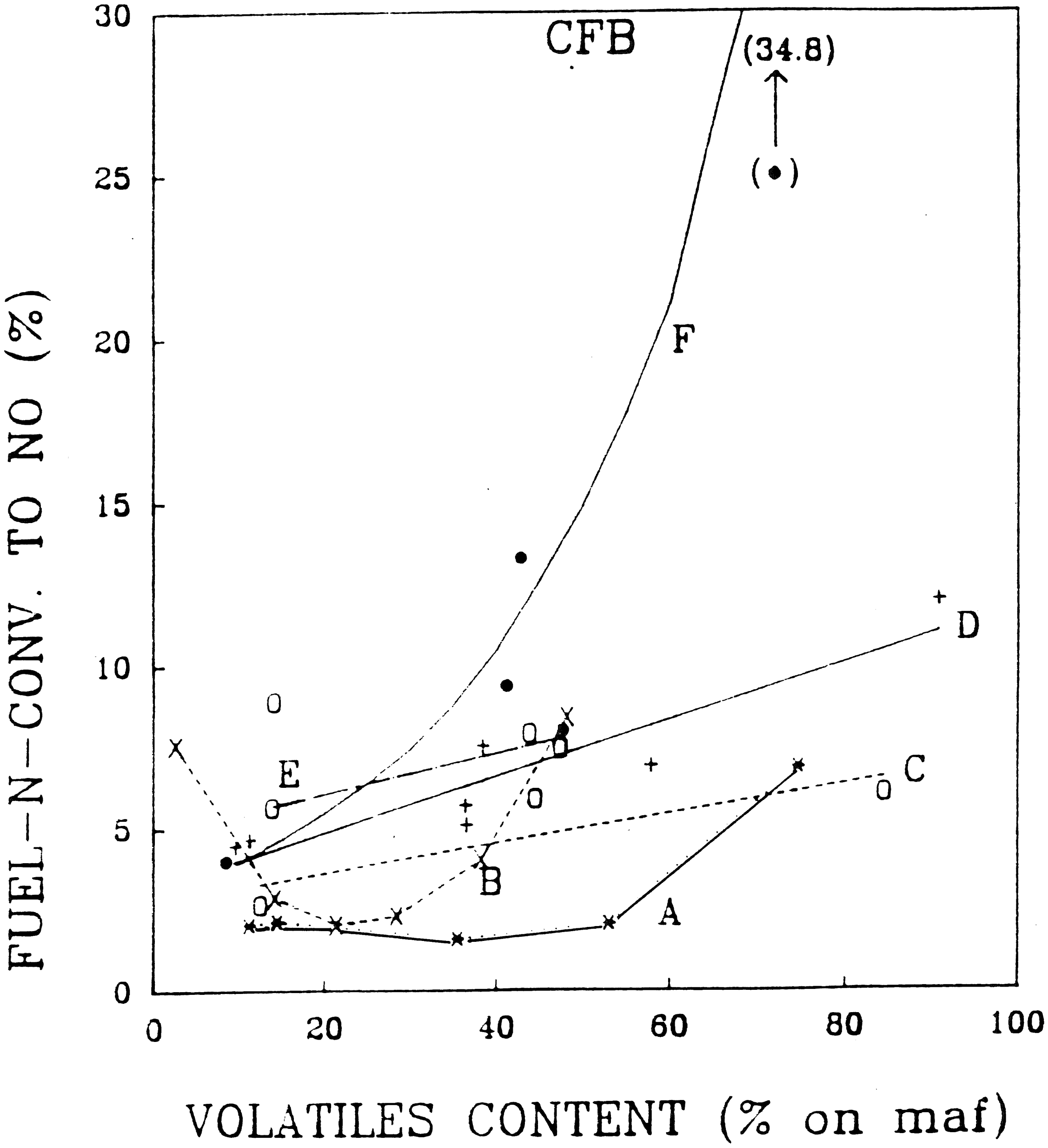


Fig. 6. Fuel nitrogen conversion to NO in different SFB combustors. Key: A - this work, B - [3], C - [6, 7], D - [5], E - [4].



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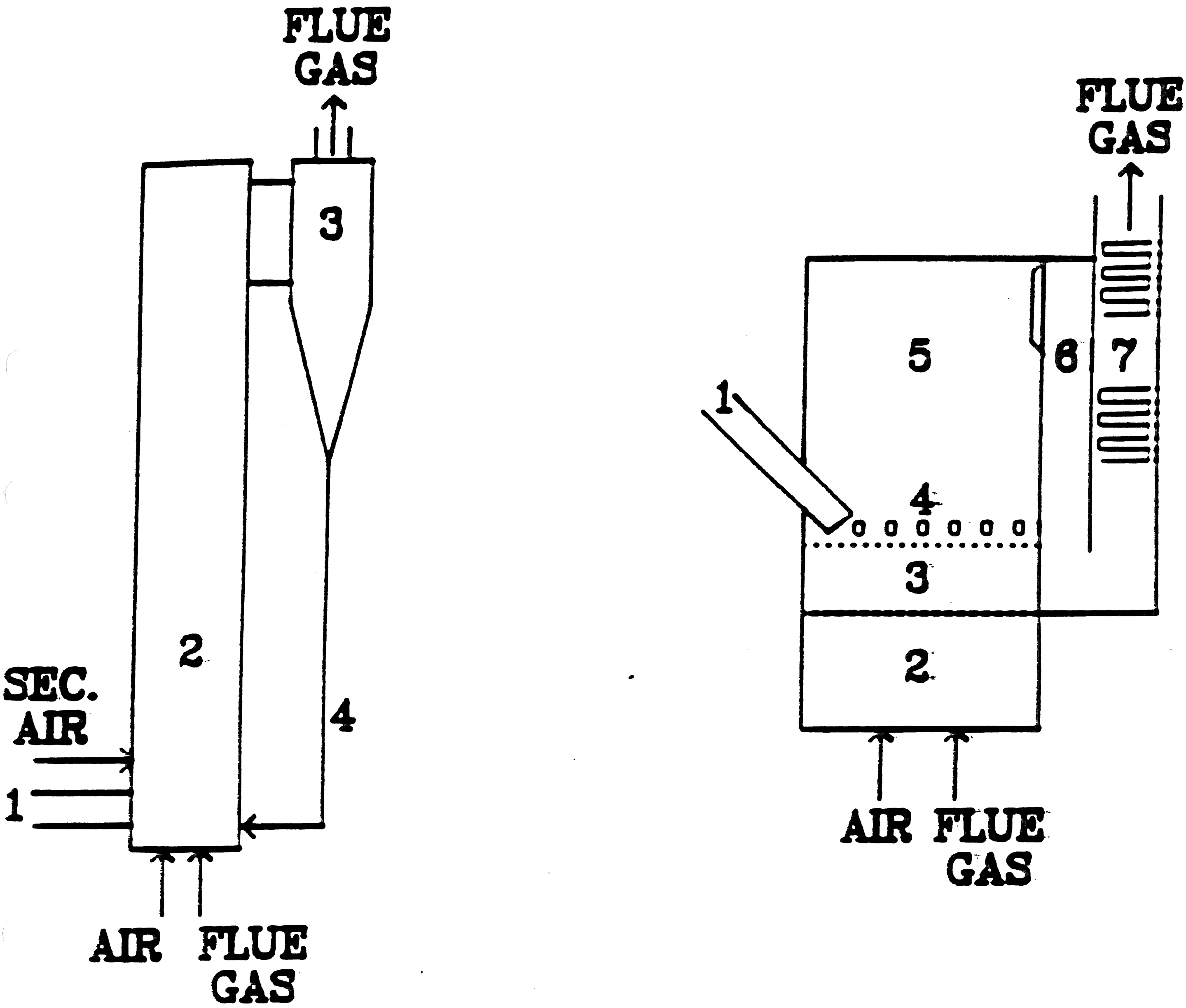

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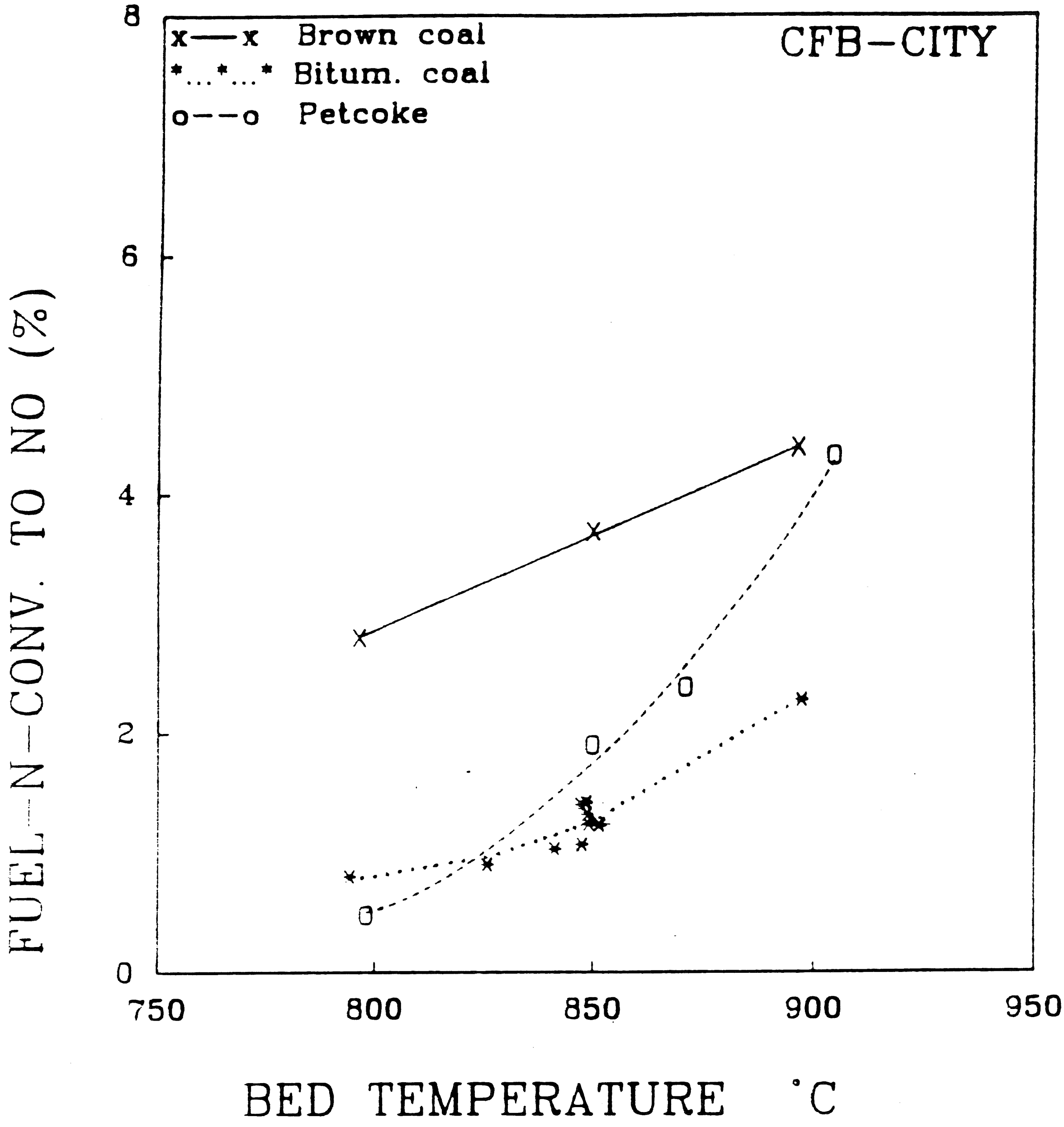

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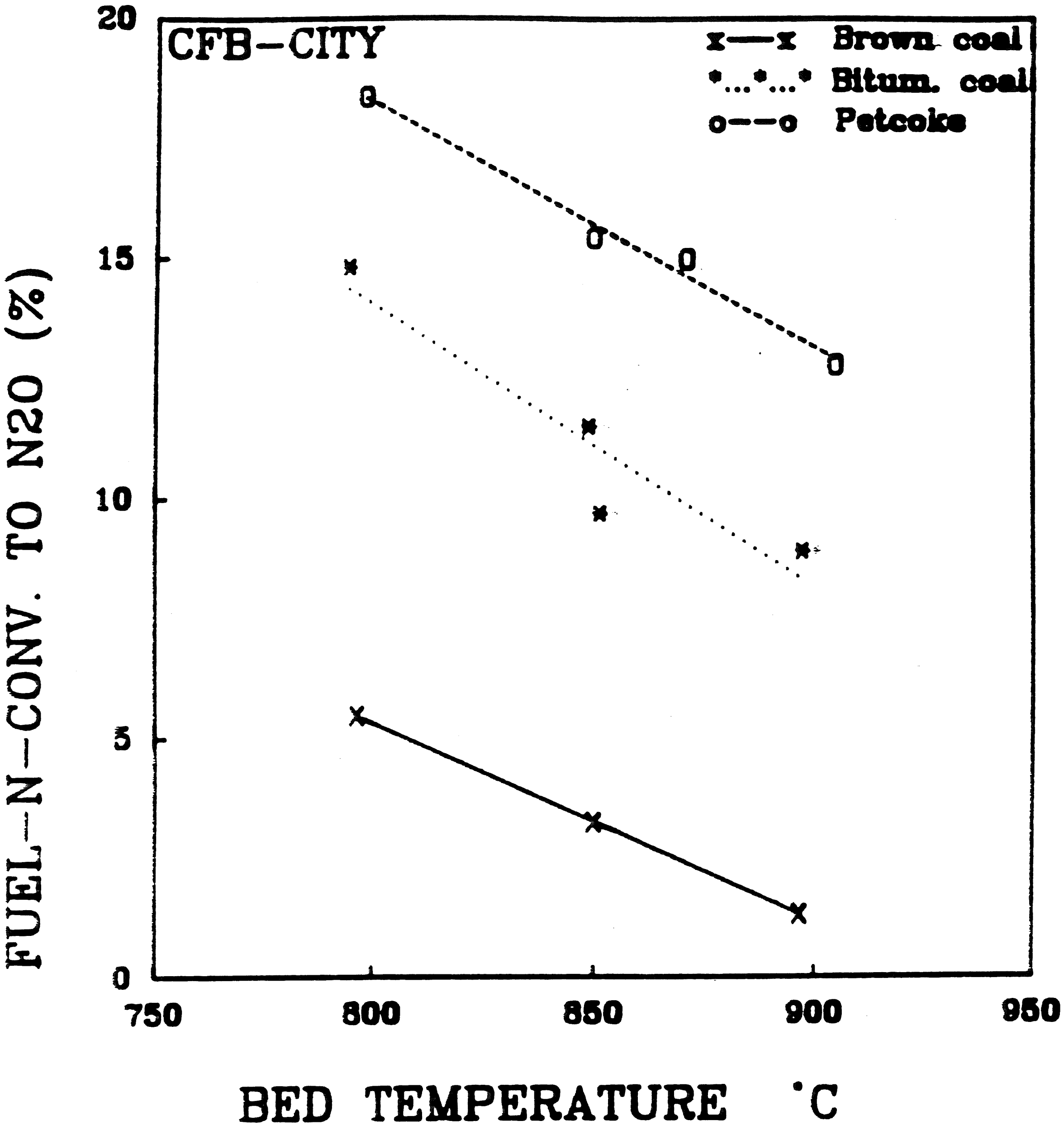

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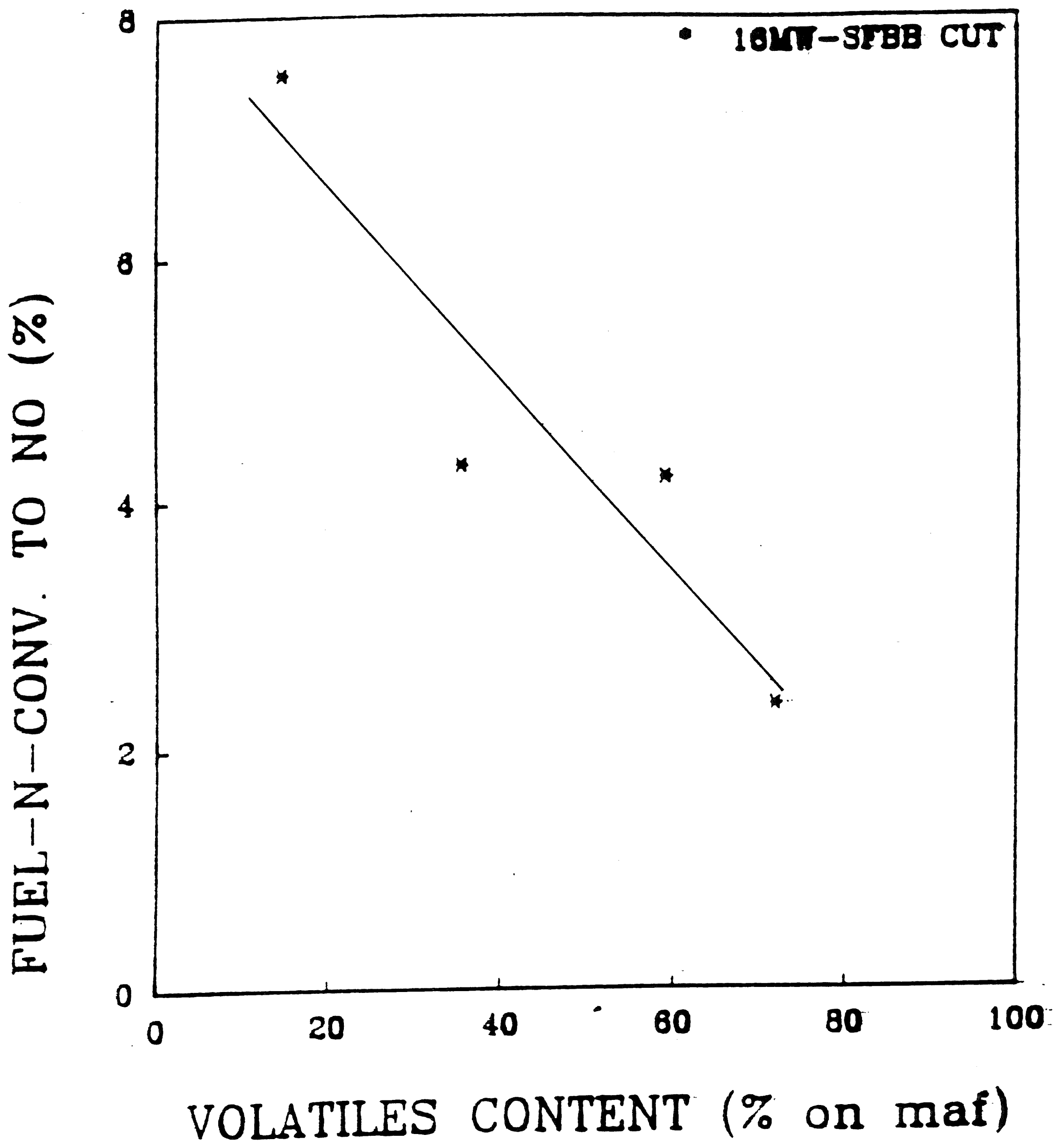

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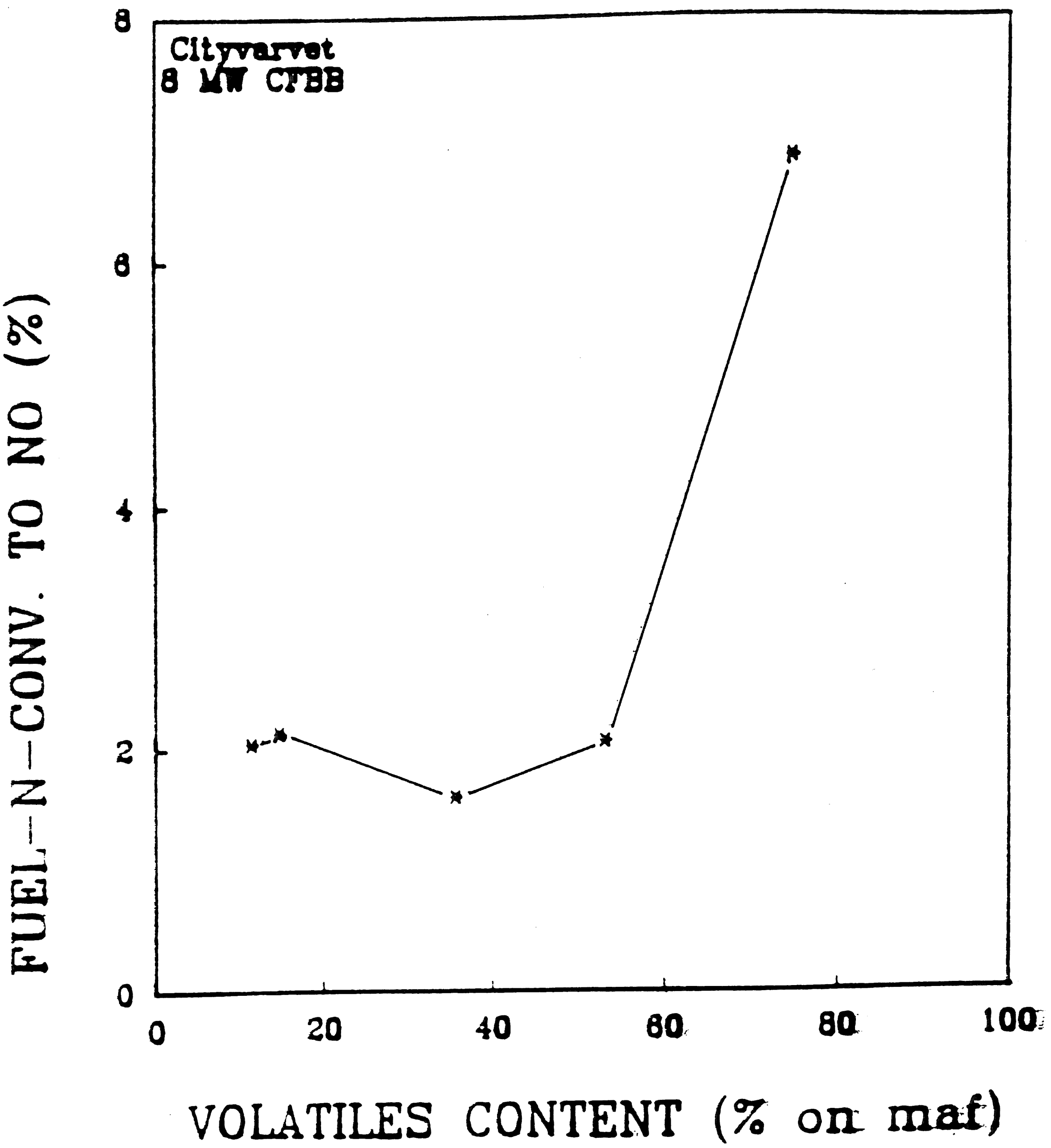

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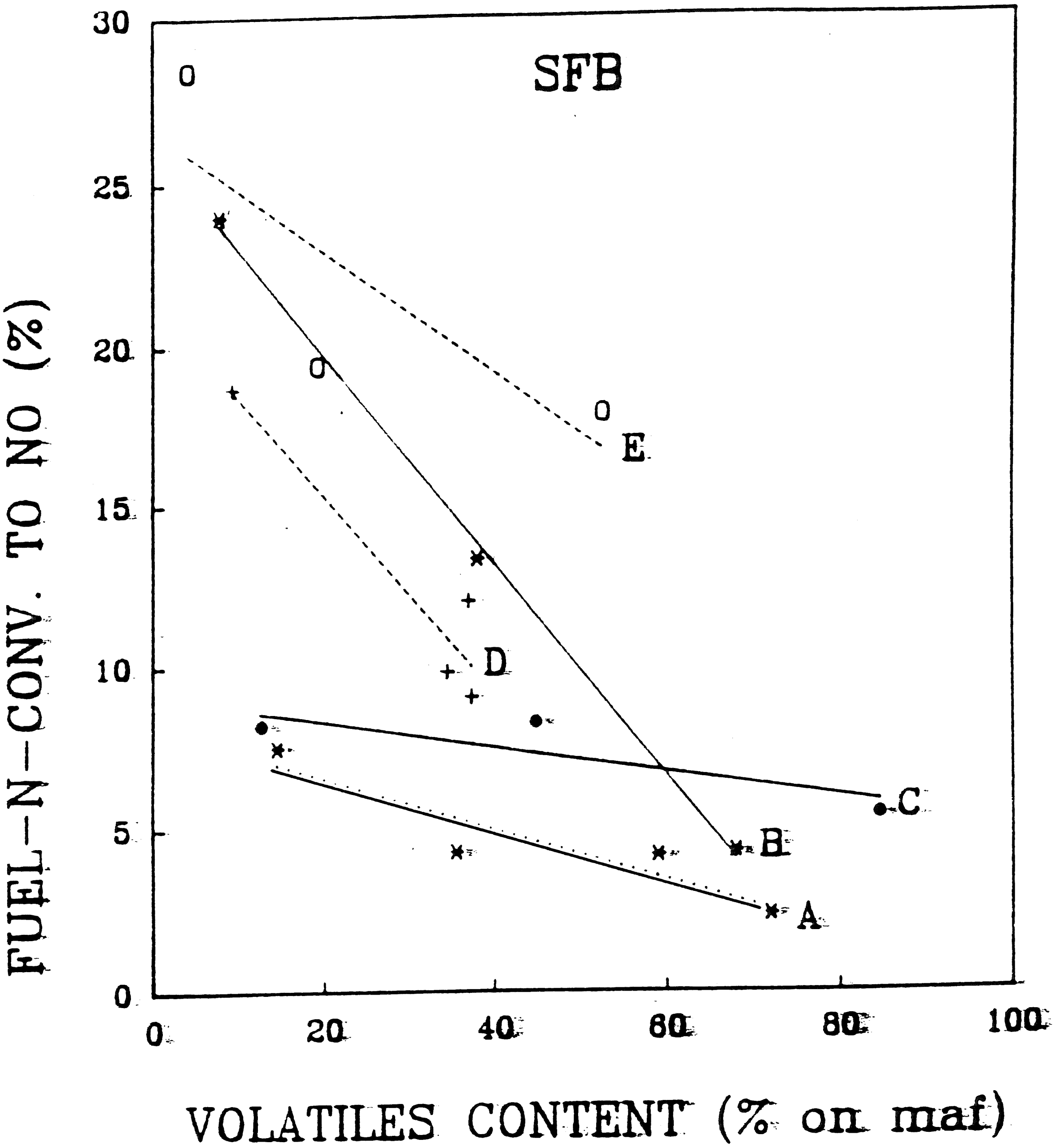

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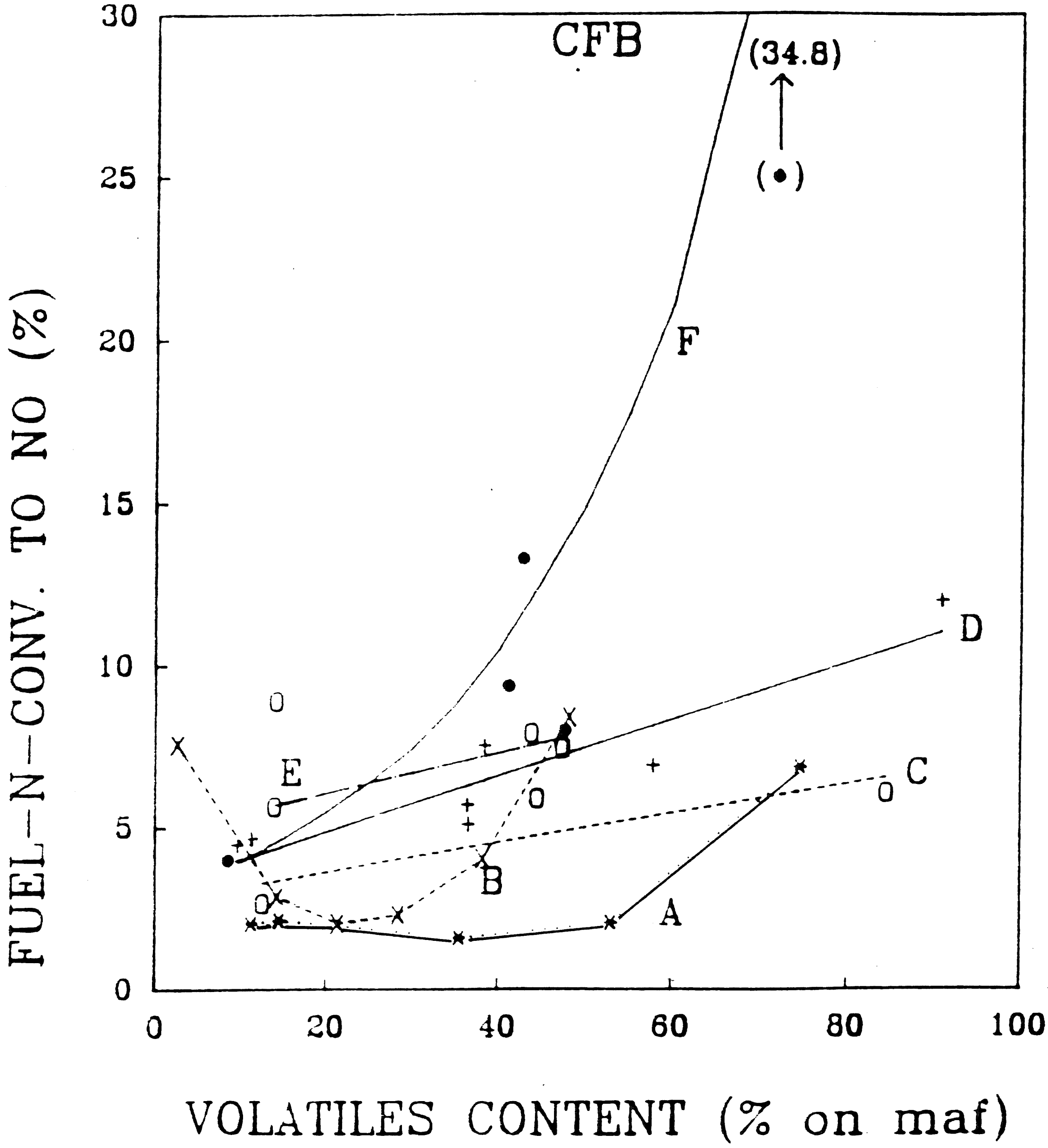

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