SO_3 REDUCTION IN THE 210 MW OIL-FIRED POWER PLANT SISAK

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Abstract

Various impacts of the combustion process parameters and burner design characteristics on the SO_3 generation in the steam generator furnace of the 210 MW oil-fired Power Plant Sisak have been studied by using 3-D mathematical modelling. Problems of the Power Plant Sisak, which burns heavy-oil fuel with 2-3% sulphur and exhibits flue gas temperatures of 135-140 °C at the exit of the regenerative Ljungstrom air-heater, are related to severe low temperature corrosion and environmental pollution. Different parameters were varied: combustion air excess ratio, spray angle of fuel injection, number of openings on the steam-pressure atomiser nozzle and fuel droplet size.

By using the FLUENT™ software package for simulation of the oil combustion process in the furnace, relatively reliable results have been obtained which favourably could be compared with scarce existing experimental data. This means that trends of influential parameters have been well predicted rather than absolute values of the same parameters. The results of the simulation showed that the excess combustion air of 1.07-1.10 could not be decreased without a reconstruction of combustors because of soot appearance and increased CO concentration. By increasing the number of nozzle openings and the fuel atomising steam pressure i.e. by decreasing the fuel droplet size, the excess air has been decreased to 1.035, which represents the upper limit of desired result. Thereby the average SO_3 concentration in flue gases was about 25-30 ppm. The variation of fuel spray angle has been found not to have any significant influence on SO_3 and CO concentrations. By major reconstruction at the air inlet and air swirl generator and by modification of the combustion control better results could be expected which would maximally reduce problems with low temperature corrosion and environment pollution.

Keywords

SO_3 reduction, low temperature corrosion, heavy-oil fuel combustion, mathematical modelling, burner optimisation

Introduction

In existing oil-fired power plants, economic reasons impose use of heavy-oil fuel, rich in sulphur. Hereby conditions for low temperature corrosion of the steam-generator cold-end are created as well as conditions for acid aggregates air pollution, which impact environment by generation of, so called, acid rain.

It is well known that the sulphur trioxide concentration, as the main cause of the low-temperature corrosion, could be decreased by improvement of the combustion process, primarily by lowering the air excess ratio. The fact that SO_3 strongly depends on the combustion mode and the surplus of air, implies that sulphur trioxide primarily arises in flame and that is in much lesser extent a consequence of the catalytic effect.

In this paper various impacts of the combustion process parameters and burner design characteristics on the SO_3 generation in the steam generator furnace of the 210 MW oil-fired Power Plant Sisak have been studied by using 3-D mathematical modelling. Problems of the Power Plant Sisak, which burns heavy-oil fuel with 2-3% sulphur and exhibits flue gas temperatures of 135-140 °C at the exit of the regenerative Ljungstrom air-heater, are related to severe low temperature corrosion and environmental pollution.

Different parameters were varied:

- combustion air excess ratio,
- spray angle of fuel injection,
- number of openings on the steam-pressure atomiser nozzle and
- fuel droplet size.

Mathematical model

A quantitative evaluation of the influence of stated parameters on SO_3 production was done by simulating the combustion process in the furnace with the FLUENT™ software package. The mixture fraction/probability density function (PDF) combustion model and the equilibrium chemistry formulation for the reacting system were used. The mixture fraction/PDF model involves the solution of transport equations for just one conserved scalar. That scalar is known as the mixture fraction *f* and is defined according to [1]:

$$f = \frac{Y_i - Y_{iO}}{Y_{iF} - Y_{iO}}$$

where Y_i represents elemental mass fraction of element *i*. Subscript *O* denotes the value at the oxidiser stream inlets and subscript *F* denotes the value at the fuel stream inlets. Based on the calculated mixture fraction distribution, individual species concentrations could be determined. Turbulent effects of the flame are accounted for by using the probability density function. Reaction mechanisms are defined by the equilibrium chemistry model, which implicates that the chemistry is fast enough to preserve chemical equilibrium at the molecular level. An algorithm based on the minimisation of Gibbs free energy [2] is used to compute species mole fractions from the mixture fraction *f*.

The Power Plant Sisak consists of the two steam generators that supply with superheated steam one 210 MWe steam turbine. The each steam generator combustion chamber has dimensions of 8.4x8.4x25.1 m^3 and enables thermal input of 300 MWt. There are two oil burners on each side wall of the chamber. The superheated steam exit temperature is 540 °C at 140 bar. The burner consists of axial/radial inflow type swirl generating register and steam atomiser (Fig. 1). Each burner is supplied with 24.52 kg/s of air (at full load with air excess ratio of 1.07), preheated to 255 °C. The airflow is dived into three streams: unswirled primary stream and then secondary and tertiary streams, which are swirled. Fuel fired in this case was heavy-oil with composition: C=84.5%, H=11.4%, S=2.98%, A=0.02%, W=0.2%, O+N=0.9%, with lower caloric value of 40486 kJ/kg and density (at 15 °C) of 946 kg/m^3. The oil preheated to 125 °C at 20 bar is atomised into fine mist by steam at 8.5 bar and 273 °C. The fuel flow through atomiser is 6.74 kg/s and amount of steam is 0.03 kg_{steam}/kg_{oil}.

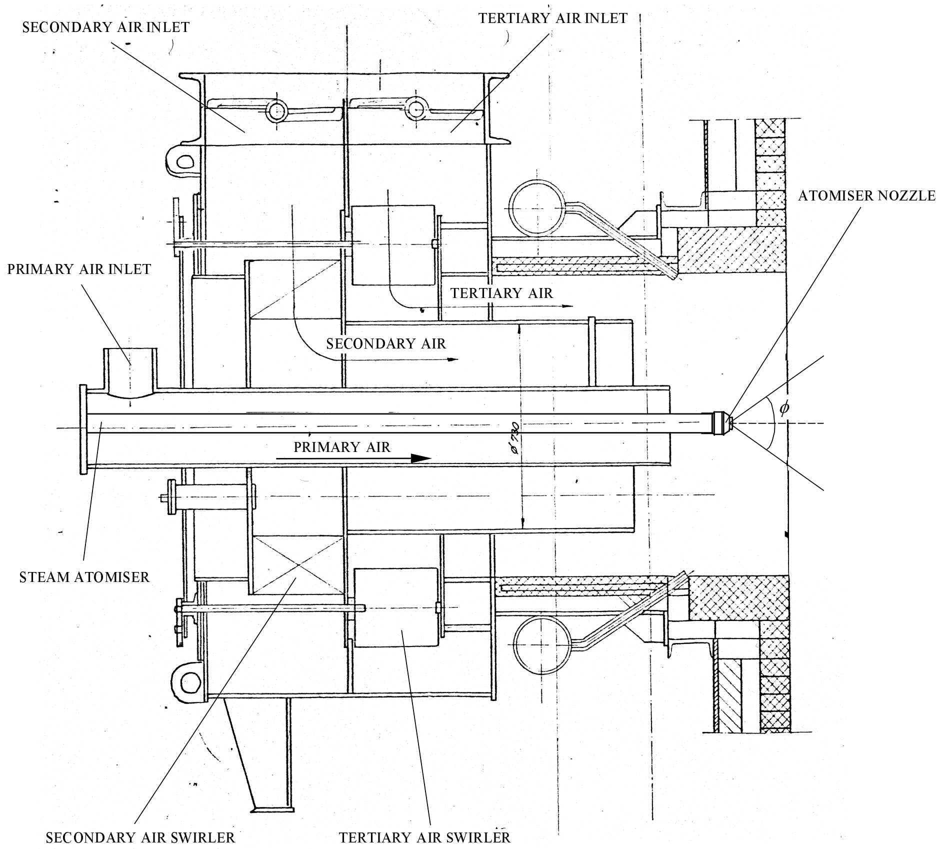

Fig. 1 Schematic of the burner

The basic idea was to modify the existing operational regime with excess air value of 1.07-1.10 to operation with surplus air of 1.035, whereby the SO_3 production would be reduced according to lesser oxygen concentration. Beforehand it was necessary to analyse different measures (related to the reconstruction of the combustors) to avoid incomplete combustion, whit a consequence of an increase of carbon monoxide concentration and the soot appearance. These measures were limited to the investigation of the fuel spray angle influence (limited with the combustors construction characteristics), the number of nozzle openings and fuel atomising steam pressure on both the SO_3 and CO production.

Results and discussion

The results of the simulations, in which important parameters were varied in order to investigate their influence on the SO_3 and CO production, were compared with the basic case values (normal operation at full load). The input parameters that define the basic case are:

- air excess ratio of 1.07,
- Y-jet angle of ϕ=110°,
- number of nozzle atomiser openings, n =20
- fuel atomising steam pressure of 8.5 bar at 273 °C

The following parameters were varied:

- air excess ratio
- fuel spray angle
- number of atomiser openings
- fuel droplet size.

Influence of combustion air excess ratio

The excess air (λ) was varied in extent from 1.01 to 1.7. It is obvious, from Fig. 2a, that the flue gas temperature at the furnace exit is increased along with the air excess ratio rise. The flue gas temperature is stabilised at approximately 970 °C for the values of excess air ratio higher than 1.1. This is some 10 °C less than measured values of 980 °C. The reason why the temperature is not decreasing with the increase of the air excess ratio (what would be normally expected) lies in the fact that the flue gas velocities within the furnace are ascending (larger quantity of air in flue gas). Due to higher flow velocities the temperature field is redistributed with the displacement of the maximal temperature zone towards the furnace exit. The flue gas velocity at the furnace exit as a function of excess air is shown on Fig. 2g. Generally speaking, flue gas temperature below 1000 °C is rather low value for oil-fired furnaces. In combination with high sulphur content in fuel, it easily leads to overproduction of SO_3. It seems that for the furnace in consideration that is the case.

By lowering the O_2 concentration in the furnace as a result of lowering the excess air (Fig. 2b) the SO_3 production was also reduced (Fig. 2c). The problem arises when lowering of the O_2 concentration leads to incomplete combustion that results in higher CO concentrations, as can be observed in Fig. 2d. The next consequence of the incomplete combustion is increase of the mixture fraction value (higher percentage of unburned fuel leaves the furnace) shown in Fig. 2f. The sulphur dioxide concentration is given in Fig. 2e. Firstly it is increased with the air excess ratio due to better combustion. After reaching its maximum (the point of the complete combustion) it is gradually decreased because of larger amount of air in flue gases.

These simulation results show that, in the existing operational regime, the air excess ratio of 1.07-1.10 could not be notably decreased without a reconstruction of combustors because of soot appearance and increase of CO concentration.

Influence of fuel spray angle

It was expected that increasing of the fuel spray angle of the steam atomiser Y nozzle would lead to shorter flame and eventually to the reduction of sulphur trioxide [6]. For this reason the fuel spray angle was varied in wide range from 55° to 135° what corresponds to standard values for Y nozzles [7]. Unfortunately, simulation has shown that almost all the variables remained unaffected by the variation of the fuel spray angle (Fig. 3b, 3d, 3e, 3f). An exception was flue gas temperature at the furnace exit that decreases with angle variation from 55° to 135° due to flame shortening (Fig. 3a). At the same time SO_3 concentration slightly increases (Fig. 3c). These changes are so small that have no significance. The fuel droplet size in this comparison was of about 50 μm size.

Influence of number of atomiser openings

An analysis of the influence of number of the nozzle openings on the furnace behaviour has shown lesser sensitivity than expected. It was presumed that increasing the number of the openings would result in decrease of SO_3 and eventually of CO. That was found to be the case for SO_3 concentration, which slightly decreased with an increase of number of the openings

(Fig. 4c). That could be explained as the consequence of better fuel dispersion and better mixing with air. Unlike the SO_3 concentration, the CO concentration remained practically unchanged with the variation in number of nozzle openings (Fig. 4d). The fuel droplet size was 50 μm.

Influence of fuel atomising steam pressure – fuel droplet size

In the steam atomisers, the oil flow is being broken up into droplets by a high velocity steam jet directed across the oil outlet channel (Y-jet). It was anticipated that better combustion could be achieved by raising the fuel atomising steam pressure, which would ultimately result in finer spraying. The steam expands, in referent case, from the pressure of 8.5 bar and temperature of 273 °C to the condition in the combustion chamber. Available enthalpy drop is 416 kJ/kg. During adiabatic expansion steam would gain critical velocity which would consequently disperse the oil into fine droplets [8]:

$$w = \varphi\sqrt{2000 \cdot \Delta h}\ \ [\mathrm{m/s}], \qquad d = \frac{0.415}{\Delta h}\ \ [\mathrm{mm}]$$

Table 1. shows droplet sizes and atomising steam velocities for various enthalpy differences:

Δh [J/kg]	w [m/s]	d [μm]
1383	45	300
2767	63	150
8300	110	50
416000	775	1

Table 1. Enthalpy differences, steam velocities and fuel droplet diameters

By decreasing the oil droplet diameter from 300 μm to 1 μm the flue gas exit temperature from the furnace lowers due to flame shortening what is shown on Fig. 5a. The combustion time decreases and the high temperature zone shifts back to the burners. Accordingly, due to lower average temperature, conversion of SO_2 to SO_3 is increased whereby the concentration of SO_3 rises (Fig. 5c). Finer oil droplet dispersion enhances combustion, so lowering of the CO concentration can be observed (Fig. 5d).

Conclusion

By using the FLUENT™ software package for simulation of the oil combustion process in the furnace, relatively reliable results have been obtained which favourably could be compared with scarce existing experimental data. This means that trends of influential parameters have been well predicted rather than absolute values of the same parameters. The results of the simulation showed that the excess combustion air of 1.07-1.10 could not be decreased without a reconstruction of combustors because of soot appearance and increased CO concentration. By increasing the number of nozzle openings and the fuel atomising steam pressure i.e. by decreasing the fuel droplet size, the excess air has been decreased to 1.035, which represents the upper limit of desired result. Thereby the average SO_3 concentration in flue gases was about 25-30 ppm. The variation of fuel spray angle has been found not to have any significant influence on SO_3 and CO concentrations. By major reconstruction at the air inlet and air swirl generator and by modification of the combustion control better results could be expected which would maximally reduce problems with low temperature corrosion and environment pollution.

List of symbols

d	fuel droplet diameter, μm
f	mixture fraction, -
Δh	enthalpy difference, kJ/kg
n	number of nozzle atomiser openings, -
t	flue gas temperature, °C
Y_i	elemental mass fraction of element i, kg/kg
w	steam velocity, m/s
ϕ	fuel spray angle, °
φ	nozzle coefficient, $\varphi = 0.85$
λ	air excess ratio, -

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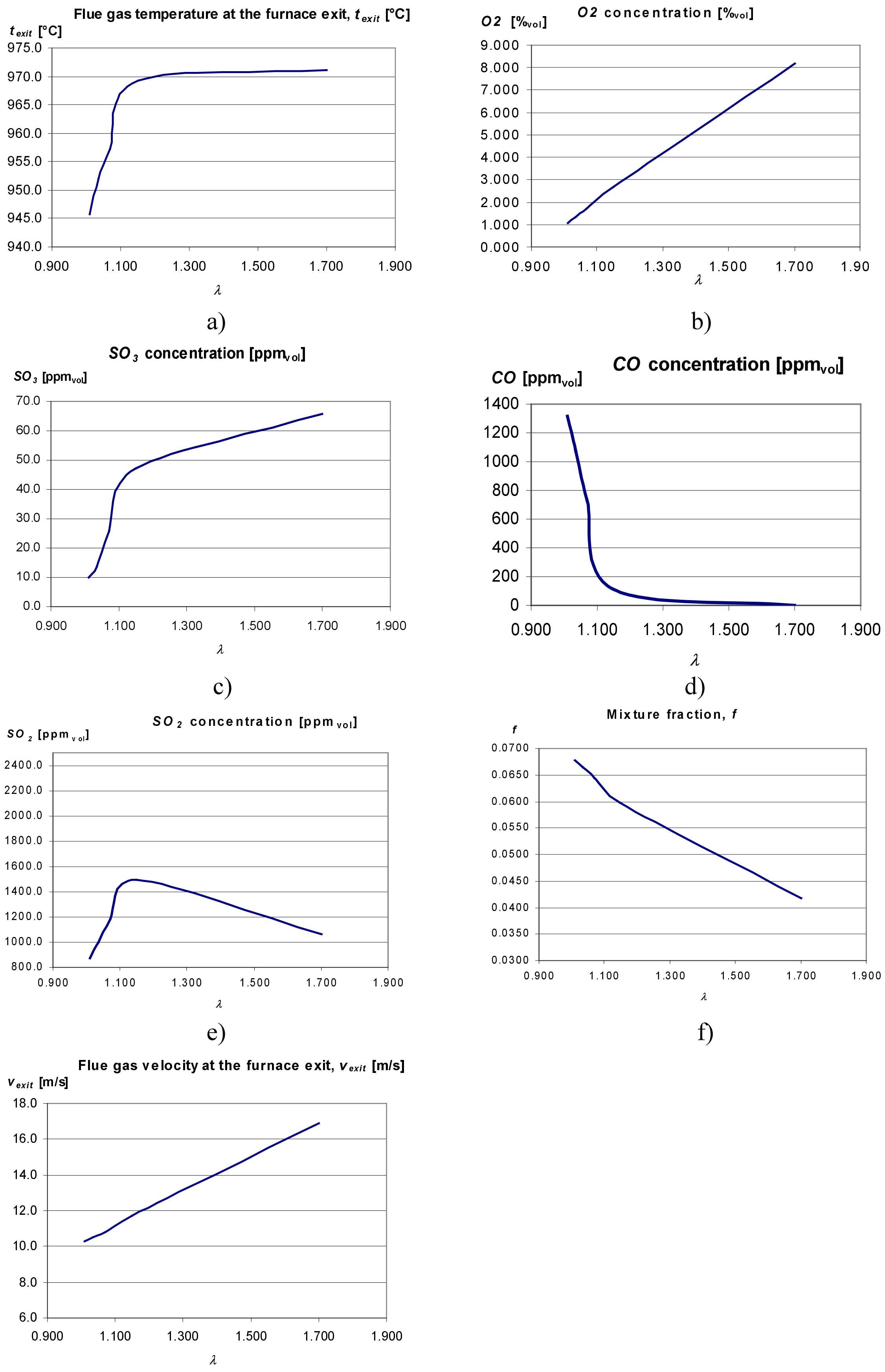

Fig. 2 Excess air influence

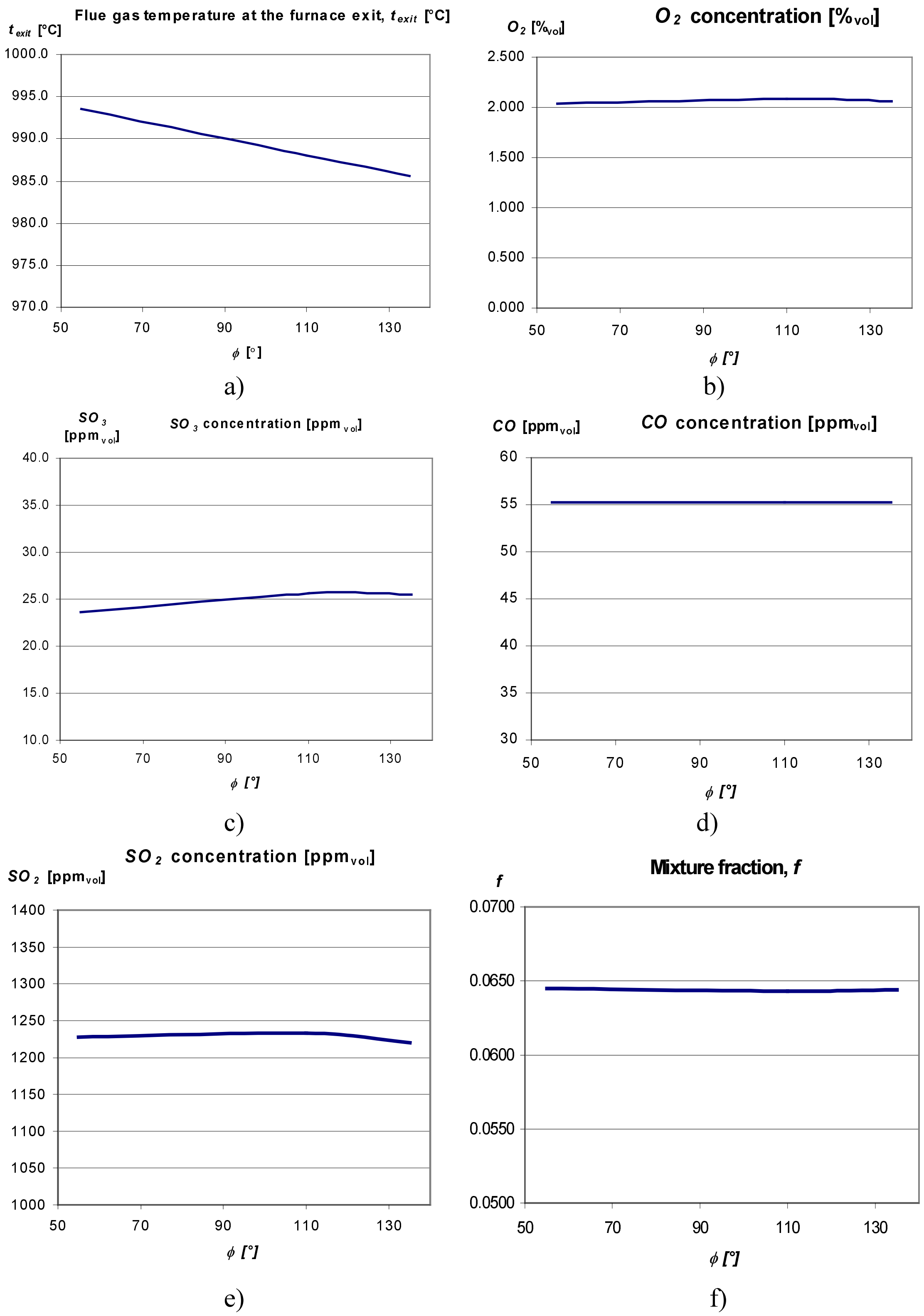

Fig. 3 Influence of fuel spray angle

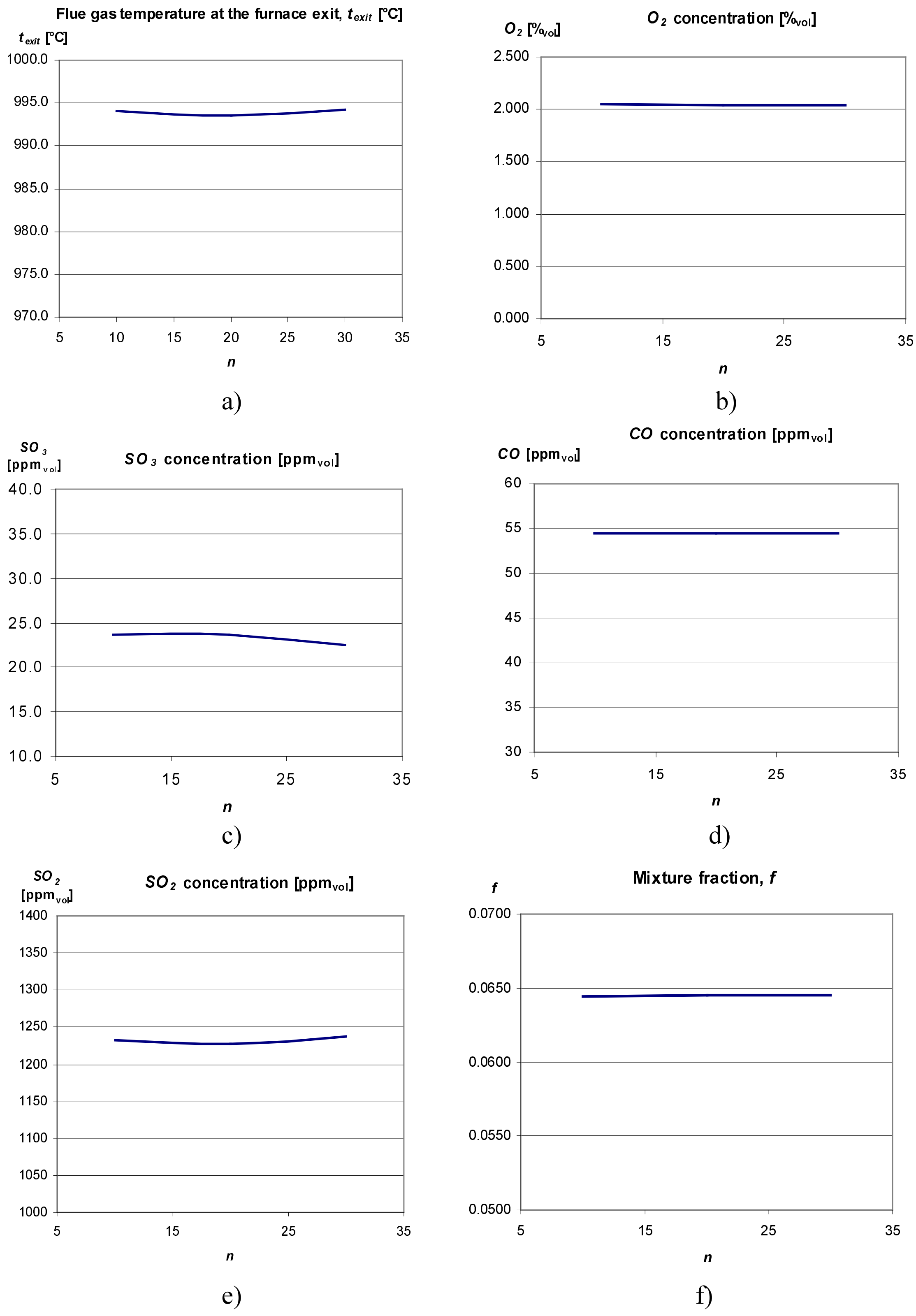

Fig. 4 Influence of number of nozzle openings

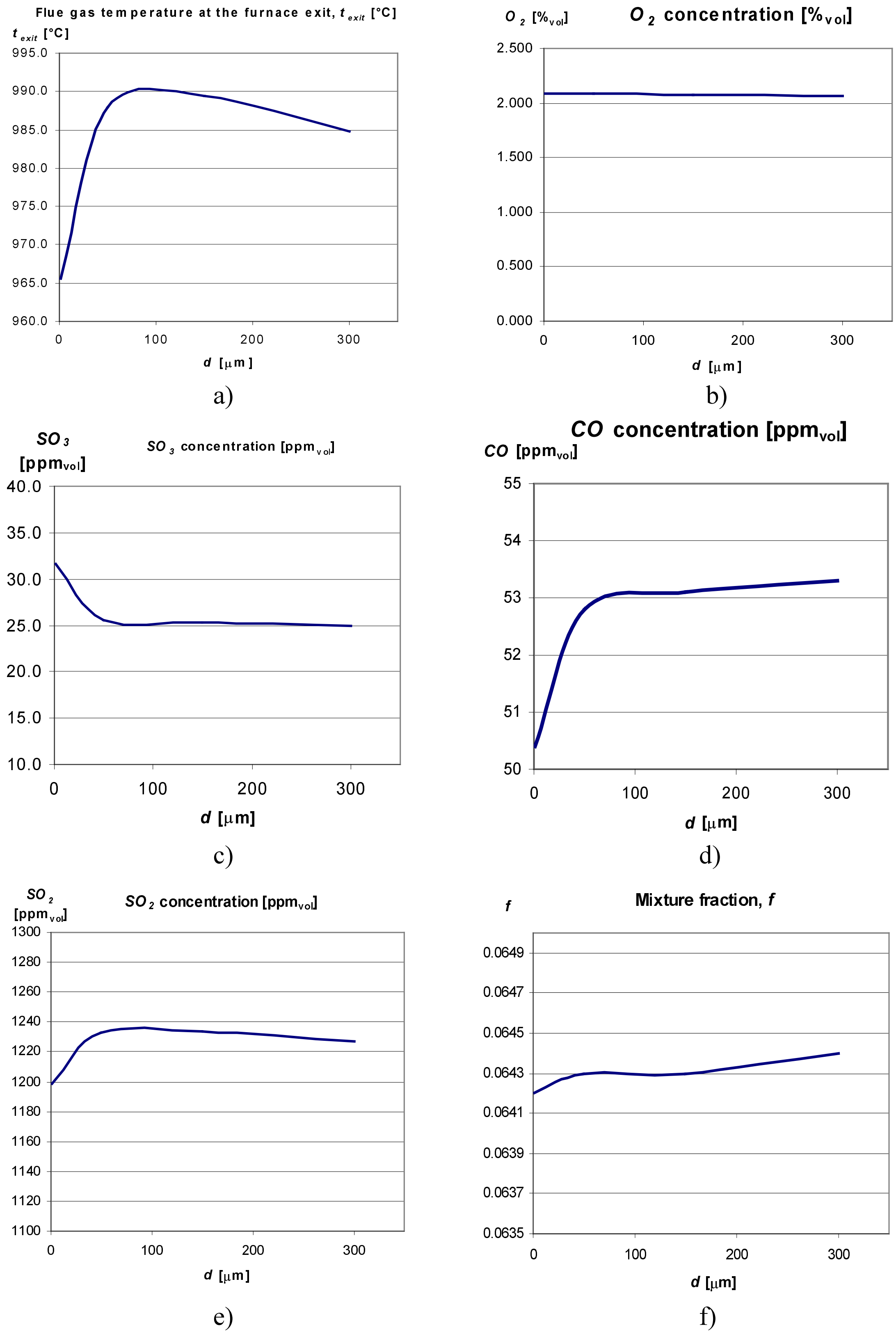

Fig. 5 Influence of fuel droplet size