PM$_{2.5}$ AND PM$_{10}$ CONCENTRATIONS FROM THE QALABOTJHA LOW-SMOKE FUELS MACRO-SCALE EXPERIMENT IN SOUTH AFRICA

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Abstract. This article presents results from the particulate monitoring campaign conducted at Qalabotjha in South Africa during the winter of 1997. Combustion of D-grade domestic coal and low-smoke fuels were compared in a residential neighborhood to evaluate the extent of air quality improvement by switching household cooking and heating fuels. Comparisons are drawn between the gravimetric results from the two types of filter substrates (Teflon-membrane and quartz-fiber) as well as between the integrated and continuous samplers. It is demonstrated that the quartz-fiber filters reported 5 to 10% greater particulate mass than the Teflon-membrane filters, mainly due to the adsorption of organic gases onto the quartz-fiber filters. Due to heating of sampling stream to 50°C in the TEOM continuous sampler and the high volatile content of the samples, approximately 15% of the particulate mass was lost during sampling. The USEPA 24-hr PM$_{2.5}$ and PM$_{10}$ National Ambient Air Quality Standards (NAAQS) of 65 $\mu$g m$^{-3}$ and 150 $\mu$g m$^{-3}$, respectively, were exceeded on several occasions during the 30-day field campaign. Average PM concentrations are highest when D-grade domestic coal was used, and lowest between day 11 and day 20 of the experiment when a majority of the low-smoke fuels were phased in. Source impacts from residential coal combustion are also found to be influenced by changes in meteorology, especially wind velocity. PM$_{2.5}$ and PM$_{10}$ mass, elements, water-soluble cations (sodium, potassium, and ammonium), anions (chloride, nitrate, and sulfate), as well as organic and elemental carbon were measured on 15 selected days during the field campaign. PM$_{2.5}$ constituted more than 85% of PM$_{10}$ at three Qalabotjha residential sites, and more than 70% of PM$_{10}$ at the gradient site in the adjacent community of Villiers. Carbonaceous aerosol is by far the most abundant component, accounting for more than half of PM mass at the three Qalabotjha sites, and for more than a third of PM mass at the gradient site. Secondary aerosols such as sulfate, nitrate, and ammonium are also significant, constituting 8 to 12% of PM mass at the three Qalabotjha sites and 15 to 20% at the Villiers gradient site.

Keywords: chemical composition, domestic coal, low-smoke fuel, PM$_{2.5}$, PM$_{10}$

1. Introduction

Residential coal combustion has been identified as one of the major contributors to elevated ambient particulate levels in the industrialized areas of South Africa. To address public health issues, low-smoke fuels were developed as alternatives to coal in order to reduce smoke emissions.
This PM$_{2.5}$ and PM$_{10}$ (particles with aerodynamic diameters less than 2.5 and 10 $\mu$m, respectively) monitoring and source apportionment study forms part of the Qalabotjha Low-Smoke Fuels Macro-Scale Experiment in South Africa. Three low-smoke fuels (Flame Africa, Chartech, and AFC) were selected according to criteria established during a preliminary study in 1996 (Engelbrecht and Swanepoel, 1997). These fuels were combusted in domestic stoves and braziers by the residents of Qalabotjha over a 10-day period during the winter of 1997. Both the fuel testing and ambient monitoring programs were extended for 10 additional days to facilitate a complete phase-out of the D-grade domestic coal.

The Qalabotjha region is known to be subjected to strong temperature inversions (10 °C) in the winter months. During the field campaign, temperatures changed from −5 °C in the early mornings to 18 °C in the middays. The region has a typical ‘Highveld’ climate which is characterised by dry cold frosty winters and by warm summers with a moderate rainfall.

The township of Qalabotjha has approximately 15 000 residents residing in approximately 2500 dwellings. The dwellings range from informal galvanised iron shanties to formal brick houses. Although electricity is available, most residents prefer to use low-cost D-grade coal for cooking and heating. Ventilation is poor, so residents are constantly exposed to emissions from residential coal combustion.

The objectives of this article are to examine the PM$_{2.5}$ and PM$_{10}$ mass and chemical compositions acquired in Qalabotjha and Villiers, and to compare results of gravimetric analysis on Teflon-membrane and quartz-fiber filters. Modeling of PM$_{10}$ along with the source apportionment results are presented by Engelbrecht et al. (1999a, b).

2. Ambient Monitoring

Qalabotjha adjoins the north-eastern Free State town of Villiers and lies along the southern bank of the Vaal River (Figure 1a), close to the N3 route from Johannesburg to Durban, and approximately 150 km to the south-east of Johannesburg. This township was selected because of its size and its general upwind position in relation to the industrialized Vaal Triangle and Mpumulanga Highveld regions of South Africa.

Four sampling sites (shown in Figure 1b) were selected, including three urban sites in the black township of Qalabotjha (Qalabotjha Police Station, Creche, and Clinic) where coal is used as the main energy source, and one gradient (Watson et al., 1997) site in the adjacent white community of Villiers where electricity is used. These four sites are within a radius of 1.2 km from each other to examine the spatial pollution variations within the neighborhood. The sampling sites were primarily selected to obtain representative measurements of study area; other considerations included the security of equipment, the availability of an uninterrupted power supply, and 24 hr accessibility by field operators.