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## **Effect of Target And Background Temperatures on Thermal Obscuring Potentials of Some Mineral Dusts**

**H. Ramzy\*, M. Sh. Fayed\*, M. K. Abd El Magid\*,  
T. Melliegy\* and K. Ali\***

### **ABSTRACT**

A promising approach to the developments of passive countermeasures against imaging infrared seekers is airborne obscurants. The effect of target and background temperatures on the thermal obscuring potentials of different mineral dusts as airborne obscurants was studied. The target temperatures and background temperatures were within the following ranges (50-200°C) and (18-35°C) respectively. The airborne smoke powder was generated pneumatically within a designed smoke tunnel equipped with means for measuring the surrounding ambient temperature. The thermal obscuring potential of the smoke was tested by using a thermal camera attached to a video recorder and a data processing system. The effect of smoke on the attenuation of infrared radiation emitted from a the target was recorded, analyzed and explained.

### **KEY WORDS**

Infrared countermeasures, powder, screening, smoke, obscurants

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\* Egyptian Armed Forces, Egypt.

## 1. INTRODUCTION

By common sense, what can be seen can be hit and killed on the battlefield. The Army uses smoke and obscurants to attack threat reconnaissance, surveillance, and target acquisition efforts. Smoke is also used to protect the forces and to support tactical deception operations. By combining obscuration with maneuver the forces could be protected and deny the threat ability to acquire and engage it [1]. Means of smoke generation developed just prior to WWII, which made it feasible to use screen smokes extensively in both offensive and defensive operations. Screening smokes were used to conceal all types of troops movements and installations in both combat zones and rear areas [2].

All sensory equipments require a certain amount of energy before they can perform their functions. A sensor will also fail to function if the level of energy, in the wavelength range that sensor is designed to work within, is too great [3]. The ability to detect and identify a target concealed by smoke cloud is a function of target to background contrast. Smoke cloud reduces the target to background contrast, making the target more difficult to be detected [4]. Recent developments in optoelectronics have led to more effective military systems designed for the detection of hostile targets [5,6].

Generation of smoke by dispersal of powders is based on production of obscuring dust clouds by the gaseous suspension of particulate material originating from the disruption of bulk solids (blasting), or from the dispersion of finely divided powders (pneumatically). Dispersal of smoke powders pneumatically could be carried out by means of positive or negative pressure systems [7-10].

Airborne obscurants could be considered as common name for most mechanical smoke systems, which concerned with aerosolize solid particles with minor dimensions below one micron. Obscurant particles are, by necessity, high-aspect ratio, electrically conductive fibers or flakes with small minor dimensions (nanoparticles are interesting candidates) [11-13]. Traditional dissemination mechanisms are explosives, and pneumatics [14]. The thermal obscuring powders could be packed in a camouflage system such as a canister, missile, rocket or a gas generator and dispersed in the atmosphere [15,16]. The aim of this work is to investigate the effect of target and background temperatures on thermal obscuring potentials of some mineral dusts.

## 2. EXPERIMENTAL WORK

### 2.1 Chemicals

All the chemicals used in this experimental work were of the commercial grade. They were used directly without any purification or treatment. These chemicals are shown in table (2.1). The choice of the investigated powders was based on recent study of obscurant materials [17], the toxic hazards, explosion hazards and availability and economic aspects [18-21]. Calcium carbonate and talc powders are inflammable and do not form explosive mixture with air but ultrafine carbon black may be ignited or explode in air at temperature above 250°C [22-24].

## 2.2 Instruments and Experimental Setup

The used instruments during different steps of the experimental work are illustrated in table (2.2). Complete specification, effective working ranges, and available diagrams of the used instruments are illustrated during the description of each step of the experimental work.

Characteristics of the produced cloud of smoke were measured by thermal imager model 760 LW Inframetrics of spectral range from 8-12 $\mu$ m. It was equipped with TV&videocassette recorder model Panasonic TC4SV10S to record the thermal image of the infrared black body radiator model Graseby201/546. Data processing and analysis were carried out with IBM computer model 300PL Pentium III series, high performance 1.2GHz processor. The relative humidity values were measured by digital thermo-hygrometer model TFA 4001. Weighing was performed using digital analytical balance type Stanton digital balance model 351BR. Drying was carried out by drying oven of type Veb-mlw model WS3.

Experimental setup consists mainly of special designed smoke tunnel, thermal imager, data acquisition system and infrared black body [25]. Its basic specifications are given in table (2.3). It is equipped with suction and recycling fans as well as measuring apparatuses to record humidity and temperature. The smoke was generated pneumatically in the tunnel by dispersion of the powder sample within sample holder which made of PVC. Figure (2.1) shows dimensional disassembly and assembly drawing of the sample holder. The maximum mass could be loaded in this holder was about 100g. Infrared black body radiator was used to represent a field target. Thermal imager and the accompanied devices for recording and processing were placed at the other end of the tunnel. An air curtain is applied in front of them to prevent the smoke from diffusion in the space of laboratory. The effect of smoke in reducing temperature and radiation level of the infrared black body radiator with time was recorded, graphed and analyzed for each smoke sample. The setup used for measurements is illustrated in figure. (2.1).

## 2.3 Experimental studying of obscuring potentials of smoke powders.

The smoke was generated in the smoke tunnel by pneumatic mechanism, where the outlet air from the tunnel blower disperses the smoke powder in the sample holder pushing it into the smoke tunnel in the front of the infrared black body radiator and so the smoke cloud is propagated in the tunnel. Thermal characterization of the smoke cloud was investigated by measuring the attenuation of the infrared radiation through the smoke cloud at different target and background temperatures.

### 2.3.1 Preparation of Smoke Powder Samples

The smoke samples before testing were dried and particle size was analyzed with sieves. The smoke samples were weighed with the following masses, 15.00g, 25.00g, 50.00g, 75.00g, and 100.00g. Five samples were prepared, since each experiment was repeated five times. Except carbon black samples are weighed with the following masses, 1.50g, 2.50g, 5.00g, 10.00g, 15.00g, and 25.00g.

### 2.3.2 Testing of Smoke Powder Samples

- (1) The sample under testing was placed in the sample holder .
- (2) The smoke tunnel circulation system and the videocassette recorder are turned on at the same time. The outlet air from the tunnel blower disperses the smoke powder sample in the sample holder pushing it into the smoke tunnel in the front of the infrared black body radiator and so the smoke cloud propagated in the tunnel.

- (3) The change in the observed temperature of the infrared black body radiator during the propagation of the smoke cloud in the tunnel and the disappearance of target thermal image is recorded on the video tape.
- (4) The setup is turned off when the observed temperature of the infrared camera reaches its initial value before testing.
- (5) The smoke tunnel circulation system is turned on again for 10 min to remove any residual powders in the tunnel from the previous experiment, and then turned off for 10 min. This step is repeated three times to insure no residuals after each experiment.
- (6) Every sample is tested five times to insure consistency and to minimize the experimental error.
- (7) After testing the sample, the smoke tunnel circulation system is turned on for 30 min then turned off for 15 min. This step is also repeated three times; assure that the infrared camera observes no change in the initial temperature of the target when circulation system is turned on with empty tunnel.

**2.3.3 Data Analysis** Experimental data was gathered by playing the videotape in a slow motion. The variation in the temperature of infrared radiator caused by the smoke sample was tabulated with respect to time. The attenuation of infrared radiation in the range of 8-14 micrometer was calculated and represented as variation of the thermal contrast of the target at certain apparent temperature, superimposed on a certain back ground temperature [25].

### 3 RESULTS AND DISCUSSION

The effect of different mass loaded of calcium carbonate, talc powder, and carbon black on the attenuation of infrared radiation emitted from infrared black body radiator at 100°C and 18°C ambient temperature is shown in figures (3.1), (3.2) , and (3.3). Table (3.1) represents a review of the obtained results. The experiments were repeated under different target temperatures and background temperatures within the following ranges (50-200°C) and (18-35°C) respectively.

Figure (3.1) shows the effect of calcium carbonate smoke clouds produced by different masses dispersed in the smoke tunnel on the thermal contrast. The maximum attenuation of thermal contrast augments from 47% to 80% with a corresponding increase in the duration of this maximum attenuation from 0.8 to 2S. respectively. By subjecting the target to talc powder as smoke producing agent with different masses, a group of curves of similar trend is shown in figure (3.2). The thermal attenuation augments from 43% to 63% with a corresponding increase in the duration of this maximum attenuation from 1.8 to 3S. respectively. By investigating the thermal obscuring potential of carbon black, higher extent of attenuation was achieved as shown in figure (3.3). As increasing the tested masses from one to 25g, the maximum thermal attenuation increased from 26 to 100% with corresponding increase in duration of these maximums attenuation from 3.1 to 7.7S.

Figure (3.4) shows the effect of different smoke concentrations of calcium carbonate, talc powder, and carbon black on the thermal contrast of the infrared radiation of a black body radiator at 100 °C and the ambient temperature was 18°C. It was found that calcium carbonate achieving minimum thermal contrast lower than talc powder. The minimum contrast achieved by calcium carbonate, talc, and carbon black were

0.1, 0.18, and zero respectively. Only 1.23 g/m<sup>3</sup> of carbon black is sufficient to achieve 100% thermal transmittance attenuation.

### 3.1 Effect of Background Temperature on Obscuring Potential

The effect of background temperature on the thermal screening properties was tested to investigate the screening efficiency in the infrared region. The initial thermal contrast between the target at 100°C and the background was 0.49, 0.44, and 0.38 corresponding to background temperatures 18, 25, and 35°C [25]. It is clear that increasing the smoke concentration, the thermal contrast between the target and the background decreases. The obtained curves show how the thermal attenuation of the examined obscuring powders could be modified with the background temperature. The selected range of temperature could represent the normal ambient temperatures during winter and summer. The graphical relation between thermal contrast of the target and background and mass concentrations of tested powders are shown in figures (3.5), and (3.6). The obtained results are summarized in table (3.2). It was concluded that the increase in background temperature affects positively on the thermal screening efficiency of the investigated powders.

Figure (3.5) shows the effect of background temperature on the attenuation of infrared radiation by calcium carbonate. The minimums thermal contrast achieved were 0.1, 0.05, and zero at background temperatures 18°C, 25°C, and 35°C respectively. The minimum smoke concentration sufficient for maximum thermal contrast attenuation was 11.3g/m<sup>3</sup> at all background temperatures. It is clear that the thermal obscuring potential of calcium carbonate smoke increased as the background temperature increased, and so it could represent successful performance of thermal screening at 35°C or higher as in summer day. By subjecting the target to talc powder as smoke producing agent at different background temperatures, a group of curves of similar trend is shown in figure (3.6). The constructed curves are dependent on background temperatures. The same principle discussed before with calcium carbonate has been applied successfully, but to a lower extent of thermal contrast attenuation using the same concentrations. The minimums thermal contrast achieved were 0.18, 0.13, and 0.07 at background temperatures 18°C, 25°C, and 35°C respectively. The minimum smoke concentration sufficient for maximum thermal contrast attenuation was 11.3g/m<sup>3</sup> at all background temperatures. Figure (3.7) shows the effect of background temperature on the attenuation of infrared radiation by carbon black smoke. The minimums thermal contrast achieved was zero at all background temperatures.

The minimum smoke concentration sufficient to achieve these minimums was 1.7 g/m<sup>3</sup>, 1.1g/m<sup>3</sup> and 0.6 g/m<sup>3</sup> respectively. It is clear that high background temperature improves the effectiveness of the tested smoke because of the thermal contrast between the target and background decreases as the background temperature increased

### 3.2 Effect of Target Temperature on Obscuring Potential

In this part of work, the effect of target temperature on the thermal screening properties was tested to measure the screening efficiency in the infrared region. The experiments were carried out at 30°C ambient temperature.

The different initial thermal contrast between the target and the background were 0.15, 0.42, and 0.7 that corresponding to initial target temperatures 50°C, 100°C and 200°C [25]. The obtained results are shown in figures (3.8), (3.9) and (3.10) and summarized in table (3.3). The photon flux emitted from a cretin target depends on its

temperature. Increasing temperature leads to increasing the photon flux emitted from the target [26]. Increasing photon flux needs more smoke to attenuate this flux. It was found that high target temperature decreases the effectiveness of the tested smoke because of the thermal contrast between the target and background increases

Figure (3.8) shows the effect of target temperature on the efficiency of calcium carbonate smoke cloud. The maximum thermal attenuation achieved was 90%, 95.2% and 100% with respect to target temperatures 200°C, 100°C, and 50°C respectively. The minimum smoke concentration sufficient to achieve these minimums was 11.3 g/m<sup>3</sup> at all target temperatures. Figure (3.9) shows the effect of target temperature on the efficiency of talc smoke cloud. The maximum thermal attenuation achieved was 58.8%, 81.7% and 86.7% with respect to target temperatures 200°C, 100°C, and 50°C respectively. The minimum smoke concentration sufficient to achieve these minimums was 11.3 g/m<sup>3</sup> at all target temperatures. Figure (3.10) shows the effect of target temperature on the efficiency of carbon black smoke cloud. The maximum thermal attenuation achieved was 100% with respect to target temperatures 200°C, 100°C, and 50°C respectively. The minimum smoke concentration sufficient to achieve these minimums was 1.7 g/m<sup>3</sup>, 1.25g/m<sup>3</sup> and 0.56 g/m<sup>3</sup> respectively.

Table (3.3) indicates the effect of target temperatures on the attenuation of infrared radiation emitted from infrared black body radiator at different temperatures by calcium carbonate, talc powder, and carbon black, at 30°C ambient temperature. The smoke concentration sufficient for 80% and 90% thermal attenuation increases as the target temperature increases. The maximum thermal contrast attenuation increases as the target temperature decreases. It was concluded that carbon black achieves the higher thermal contrast attenuation for all target temperature. Calcium carbonate achieves 100% thermal contrast attenuation for target temperature 50°C

#### 4 CONCLUSIONS

The experimental results and theoretical discussions indicate the capability of experimentally studying the potential of various powders as infrared obscuring agents and investigate their obscuring potentials under the effect of different target and background temperatures

The main conclusions of the present work are:

- [1] The increase in background temperature affects positively on the infrared obscuring potential of the smoke cloud, and the increase in target temperature affects negatively on the infrared obscuring potential of the smoke cloud
- [2] Carbon black shows the best obscuring potentials for all target and background temperatures, even at high target temperatures and cold background temperatures.
- [3] Calcium carbonate could achieve acceptable obscuring potentials at relatively low target temperatures and high background temperatures.
- [4] The obscuring potentials of talc enhancement at relatively low target temperatures and high background temperatures, but with lower extent than calcium carbonate

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Table (2.1) Chemicals used in the present work and their toxicity limits [18-22].

Smoke producing powder	Calcium carbonate	Talc powder (Magnesium silicates)	Carbon black
Chemical formula	CaCO <sub>3</sub>	Mg <sub>3</sub> Si <sub>4</sub> O <sub>10</sub> (OH) <sub>2</sub>	C
M <sub>wt</sub> (g/mol)	100.09	379.29	12.011
Particle size range(μm)	0.2-30	10-40	1.4-25
Density (g/cm <sup>3</sup> )	2.93	2.7-2.8	1.8 - 2.1
TLV (mg/m <sup>3</sup> )	15	2.5	3.5
Supplier	MENA company (Egypt)	EJICM company (Egypt)	Columbian chemical company (USA)

Table (2.2) Instruments used in the present experimental work.

No	Instruments	Model	Using
1	Thermal imager	Inframetrics 760 LW	Experimental setup
2	TV videocassette recorder	PanasonicTC-14SV10S	Experimental setup
3	Infrared black body radiator	Graseby201/546	Experimental setup
4	Sample holder	Local fabrication	Experimental setup
5	Smoke tunnel	Local fabrication	Experimental setup
6	Digital thermo-hygrometer	TFA 4001	Experimental setup
7	Wind velocity meter	Waren H128	Experimental setup
8	PC computer	Pintum III 300PL	Data Analysis
9	Digital balance	Stanton 351BR	Sample preparation
10	Drying oven	VEB-MLW WS3	Sample preparation
11	Dental vibrator( Sieving)	DV34	Sample preparation
12	Mixing unit (rotating drum)	Local	Sample preparation

Table (2.3) Basic specification of the used smoke tunnel [25].

Item	Specification
Material	iron sheets
Cross-section	0.8 X 0.8 m
Length	6 m
Average air velocity	0.4m/s
Total volume	8.85m <sup>3</sup>
Blower power	2hp

Table (3.1) the effect of different mass loaded of calcium carbonate, talc powder, and carbon black on the attenuation of infrared radiation emitted from infrared black body radiator at 100°C and 18°C ambient temperature.

Smoke powder	Calcium carbonate					Talc powder					Carbon black					
	15	25	50	75	100	15	25	50	75	100	1	2.5	5	10	15	25
Mass loaded in the smoke tunnel (g)	15	25	50	75	100	15	25	50	75	100	1	2.5	5	10	15	25
Time sufficient for 80% attenuation (S..)	----	-----	---	9	8	--	--	--	--	--	---	--	7	3.5	2.5	1.2
Time duration for 80% attenuation (S..)	----	-----	--	4	11.3	--	--	--	--	--	---	--	20	37.5	44.5	53.8
Time sufficient for 90% attenuation (S..)	----	-----	--	--	--	--	--	--	--	--	---	--	11.5	5.5	4.3	3
Time duration for 90% attenuation (S..)	----	-----	--	--	----	--	--	--	--	--	---	--	5	25.5	30.5	52
The proposed maximum mass concentrations (g/m <sup>3</sup> )	1.7	2.8	5.6	8.5	11.3	1.7	2.8	5.6	8.5	11.3	0.11	0.28	0.56	1.13	1.7	2.8
Maximum attenuation (%)	48	57	67	73	80	43	50	59	61	63	39	53	82	98	100	100
Time duration for maximum attenuation (S..)	0.8	1	1.1	1.3	2	1.8	2.1	2.4	2.6	3	4	5.5	6	7	12	18

Table (3.2) The effect of different background temperatures on the attenuation of infrared radiation emitted from black body radiator at 100°C by calcium carbonate and talc powder.

Smoke powder	Calcium carbonate			Talc powder			Carbon black		
	18°C	25°C	35°C	18°C	25°C	35°C	18°C	25°C	35°C
Background temperatures	18°C	25°C	35°C	18°C	25°C	35°C	18°C	25°C	35°C
Smoke concentration sufficient for 80 % thermal contrast attenuation. (g/m <sup>3</sup> )	11.3	9	5.2	----	----	6.5	0.39	0.44	0.53
Smoke concentration sufficient for 90 % thermal contrast attenuation. (g/m <sup>3</sup> )	---	----	6.5	----	---	---	0.45	0.53	0.76
Maximum thermal contrast attenuation (%)	80	88.6	100	63	70	86.8	100	100	100
Minimum Smoke concentration sufficient for maximum thermal contrast attenuation. (g/m <sup>3</sup> )	11.3	11.3	11.3	11.3	11.3	11.3	1.7	1.1	0.6

Table (3.3) the effect of different target temperatures on the attenuation of infrared radiation emitted from infrared black body radiator at different temperatures by calcium carbonate, talc powder, and carbon black, at 30°C ambient temperature.

Smoke powder	Calcium carbonate			Talc powder			Carbon black		
	200°C	100°C	50°C	200°C	100°C	50°C	200°C	100°C	50°C
Target temperatures	200°C	100°C	50°C	200°C	100°C	50°C	200°C	100°C	50°C
Smoke concentration sufficient for 80% thermal contrast attenuation. (g/m <sup>3</sup> )	9.55	6.3	6.2	---	11.2	6.3	0.62	0.52	0.38
Smoke concentration sufficient for 90% thermal contrast attenuation. (g/m <sup>3</sup> )	11.3	9.3	9.1	---	---	---	0.85	0.8	0.45
Maximum thermal contrast attenuation (%)	90	95.2	100	58.8	81.7	86.7	100	100	100
Minimum concentration sufficient for maximum attenuation.(g/m <sup>3</sup> )	11.3	11.3	11.3	11.3	11.3	11.3	1.7	1.25	0.56

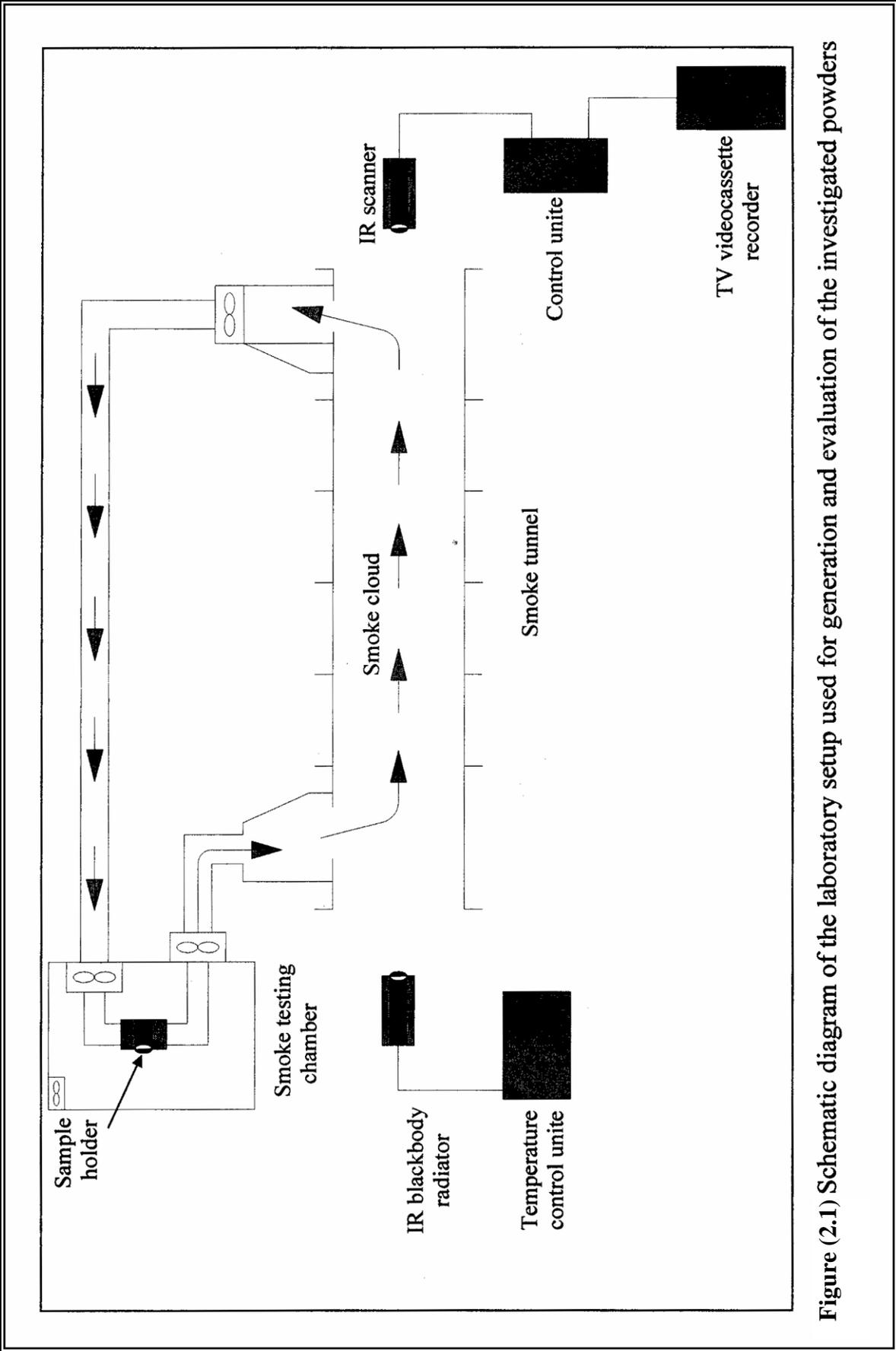


Figure (2.1) Schematic diagram of the laboratory setup used for generation and evaluation of the investigated powders

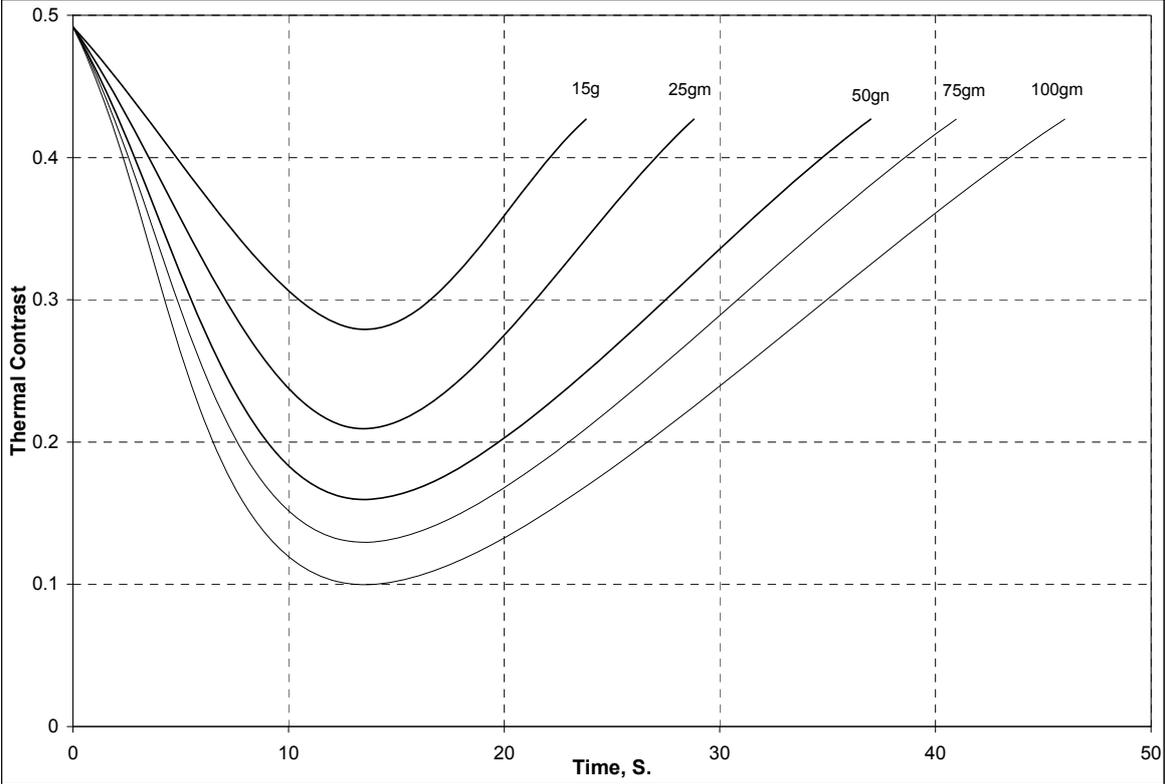


Figure (3.1) The attenuation of infrared radiation emitted from black body radiator at 100oC by calcium carbonate at 18oC ambient temperature

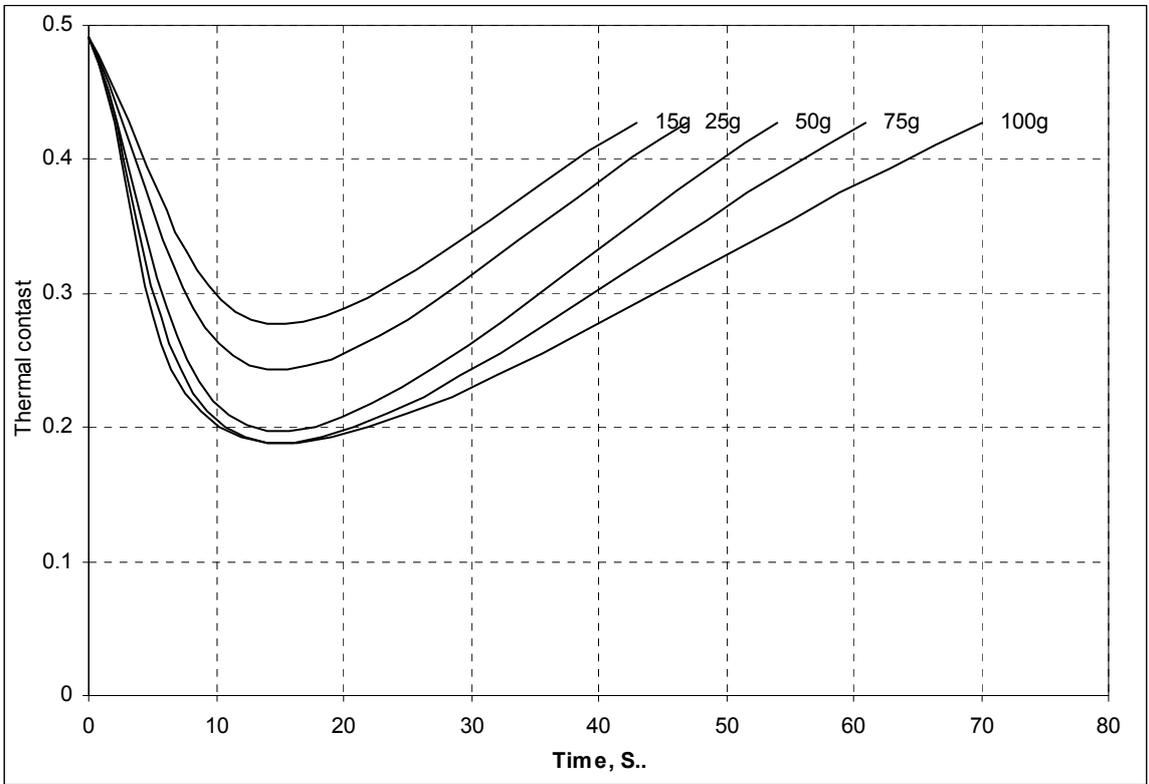


Figure (3.2) The attenuation of infrared radiation emitted from black body radiator at 100oC by talc powder at 18oC ambient temperature

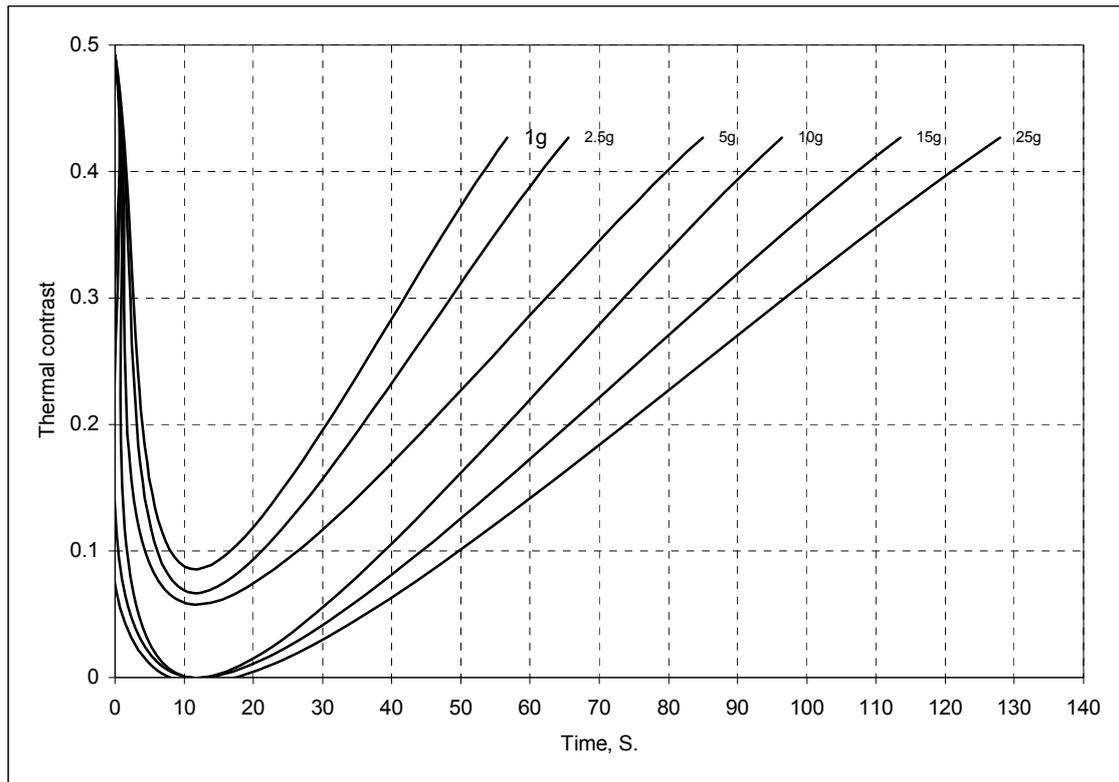


Figure (3.3) The attenuation of infrared radiation emitted from black body radiator at 100oC by carbon black at 18oC ambient temperature.

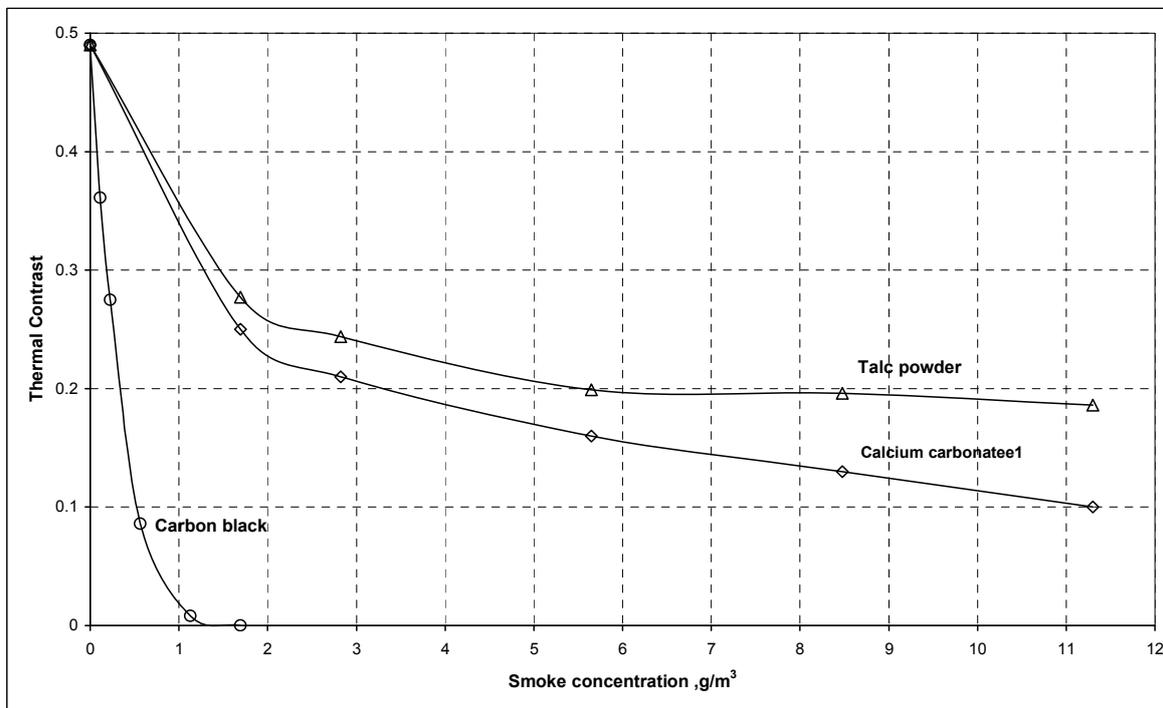


Figure (3.4) The effect of calcium carbonate, talc powder, and carbon black smoke concentrations on the thermal contrast of infrared radiation of black body at temperature 100oC and 18oC ambient temperature.

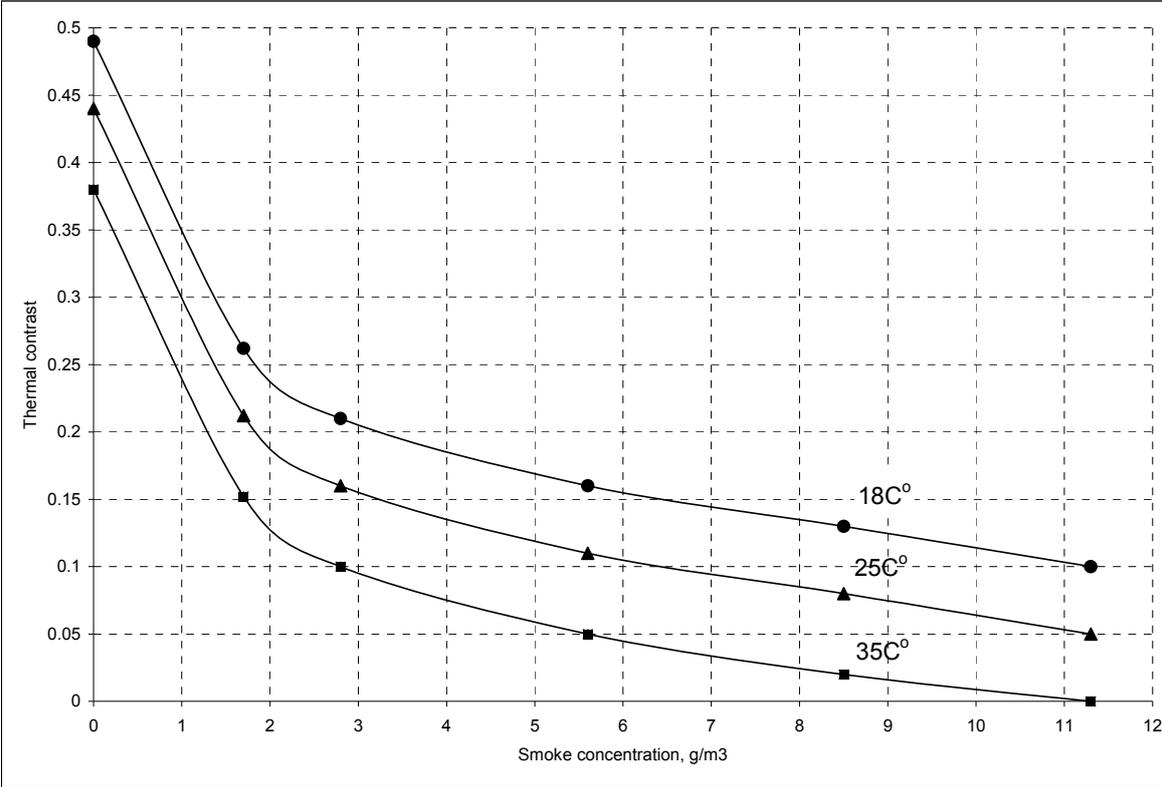


Figure (3.5) The attenuation of infrared radiation emitted from black body radiator at 100oC by calcium carbonate at different background temperatures

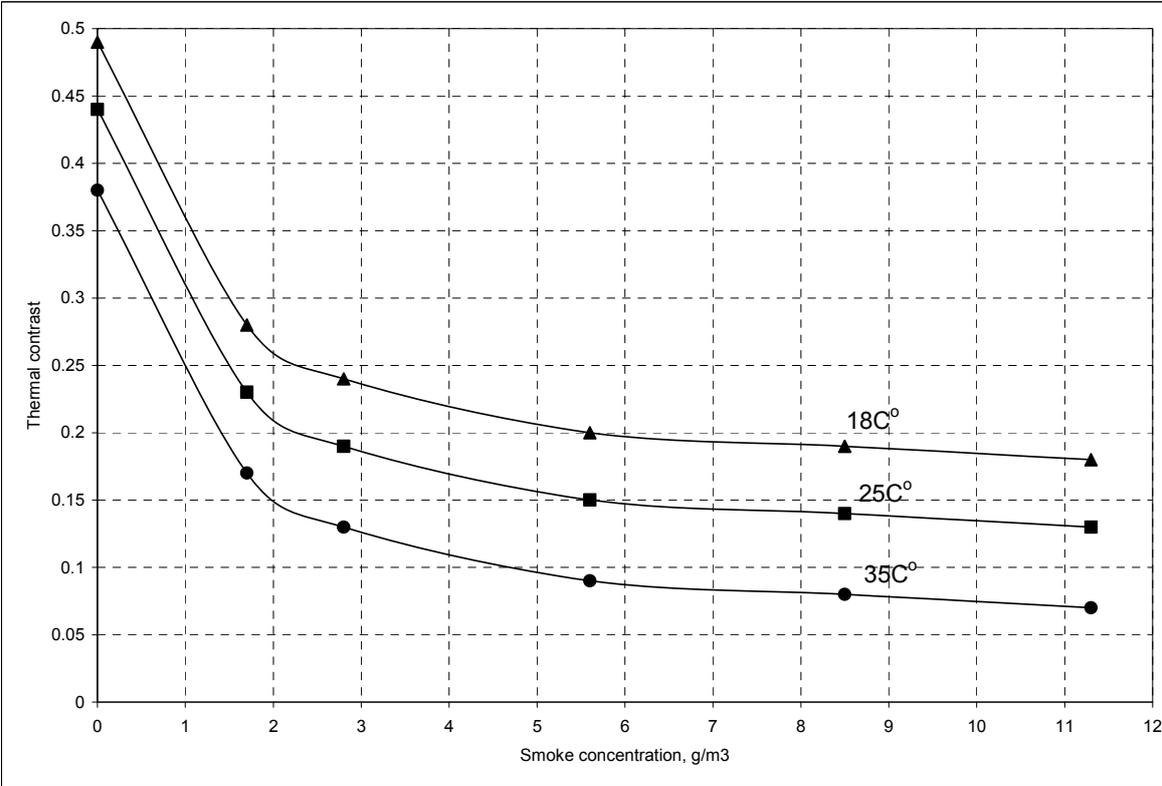


Figure (3.6) The attenuation of infrared radiation emitted from black body radiator at 100oC by talc powder at different background temperatures

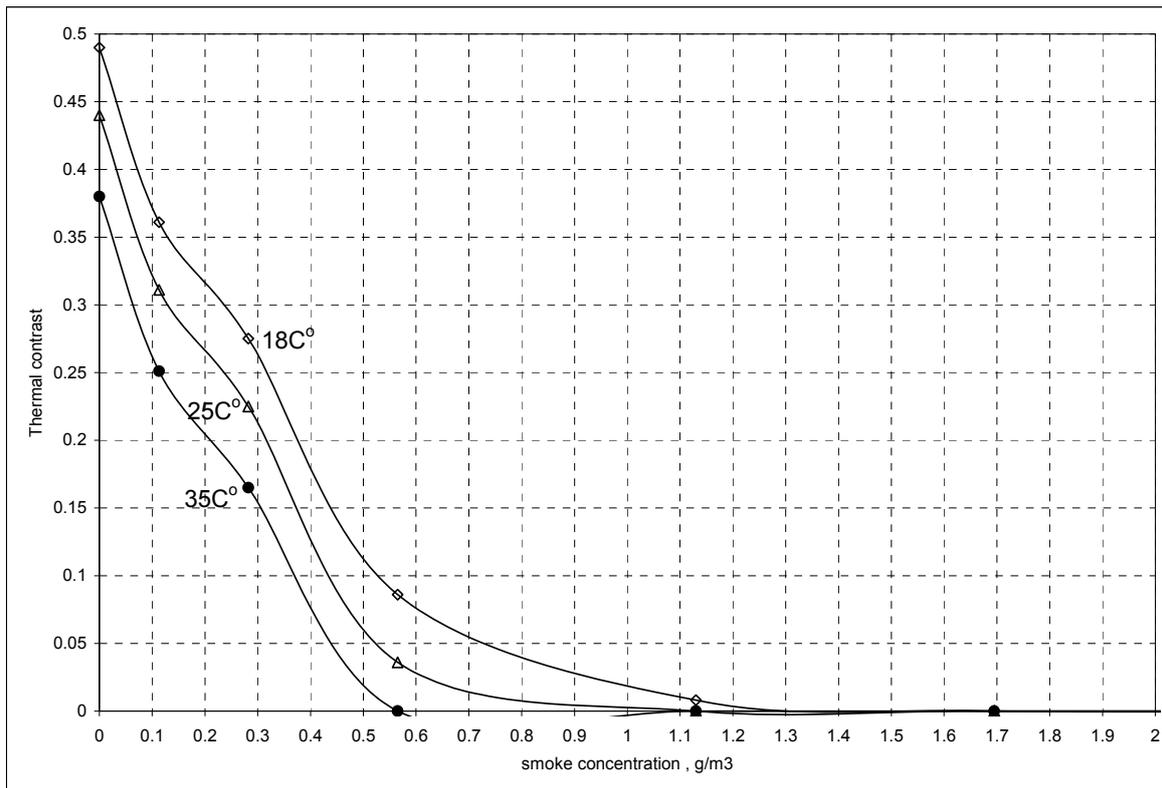


Figure (3.7) The attenuation of infrared radiation emitted from black body radiator at 100°C by carbon black powder at different background temperatures

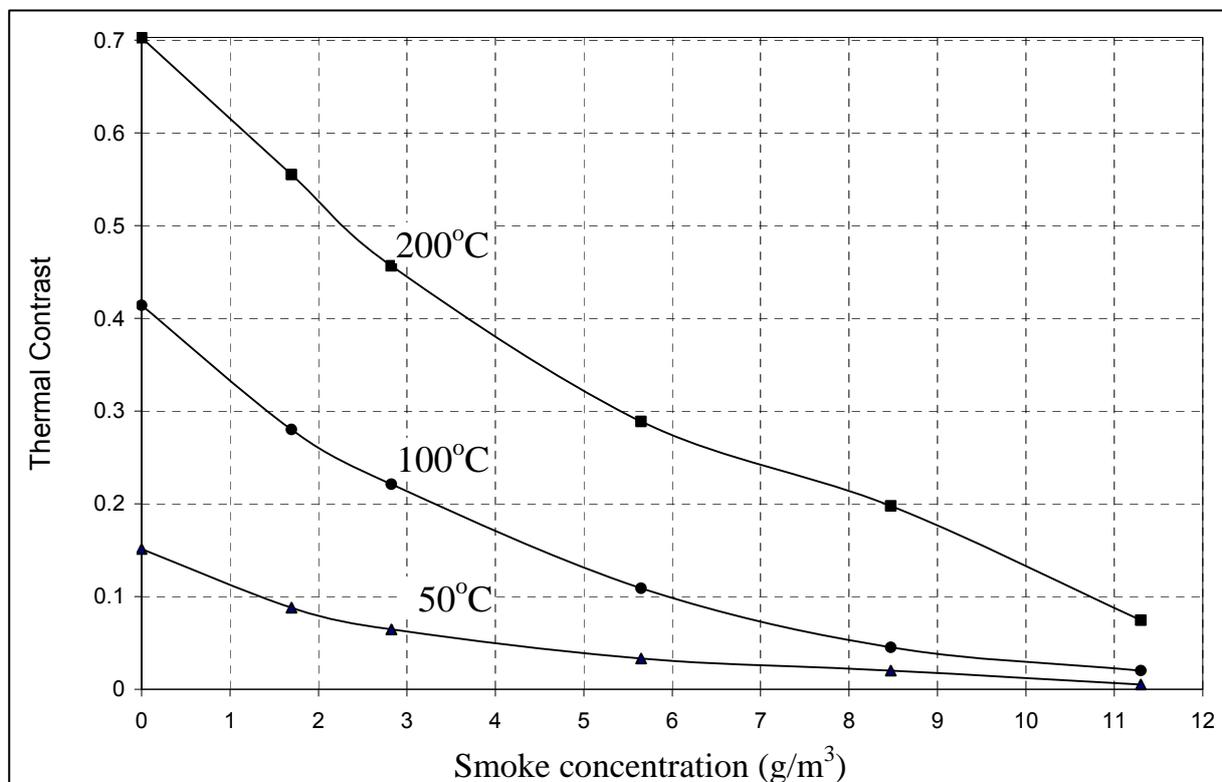


Figure (3.8) The attenuation of infrared radiation emitted from black body radiator at different temperatures by calcium carbonate. Ambient temperature 30°C and relative humidity 50%

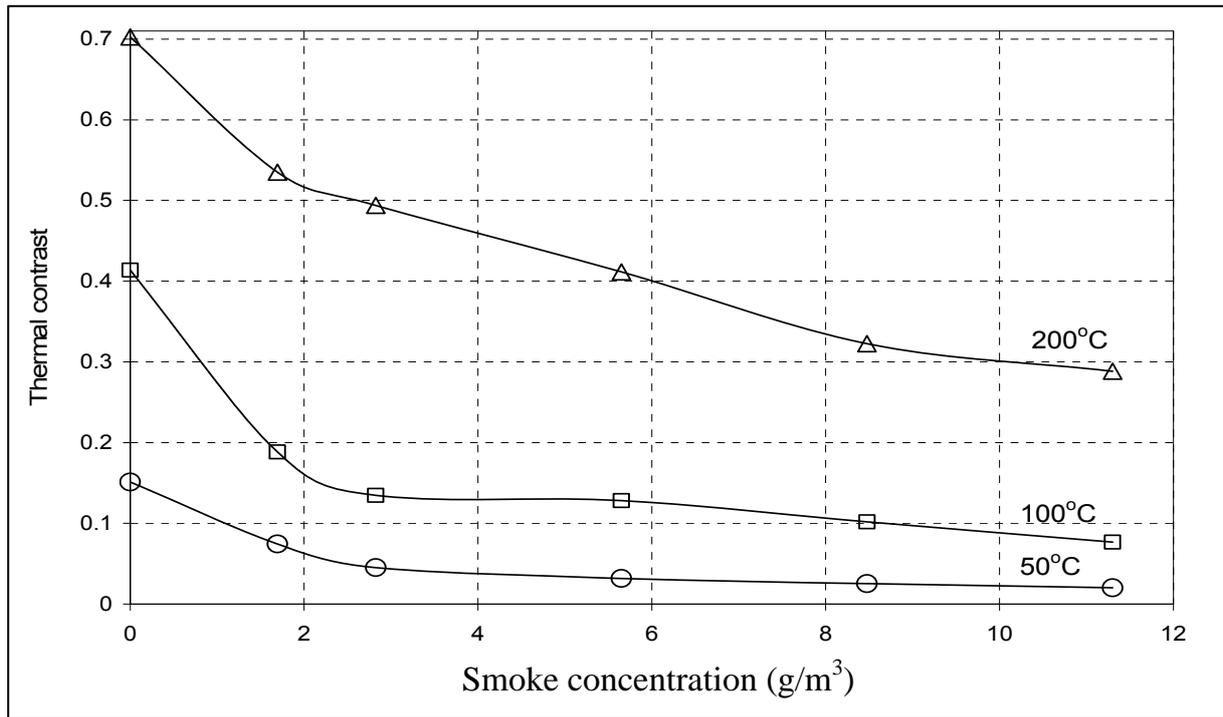


Figure (3.9) The attenuation of infrared radiation emitted from black body radiator at different temperatures by talc powder. Ambient temperature 30oC and relative humidity 50%

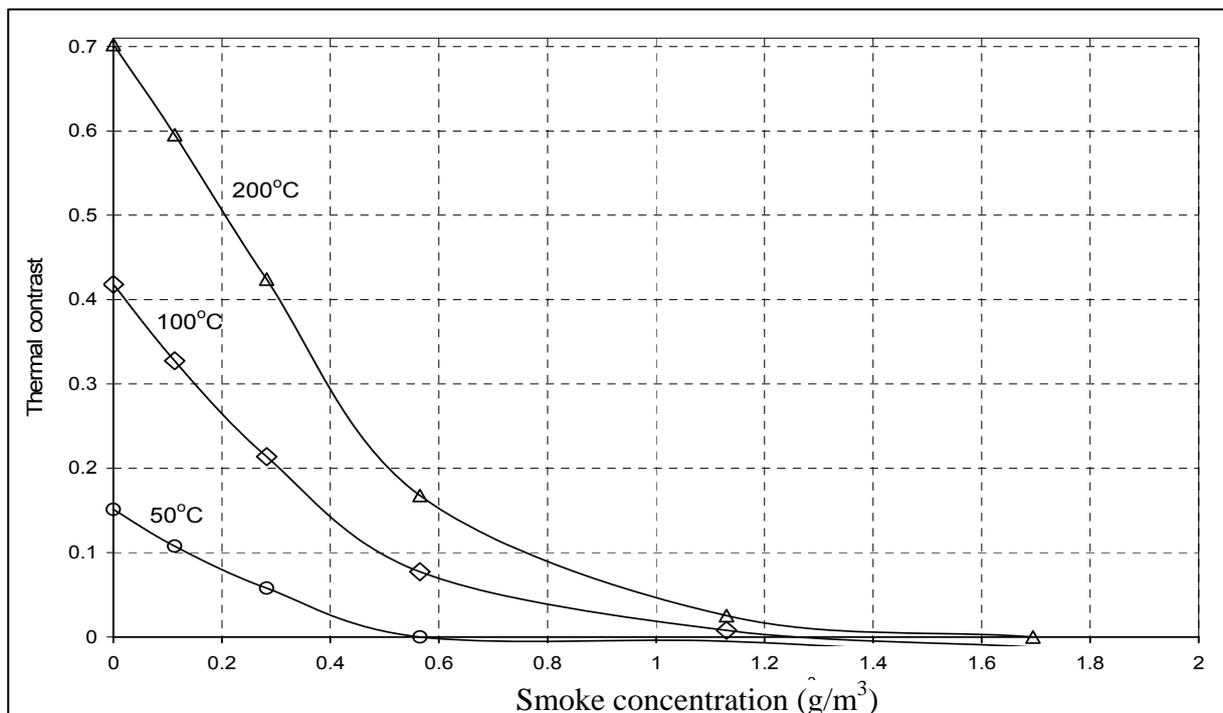


Figure (3.10) The attenuation of infrared radiation emitted from black body radiator at different temperatures by carbon black. Ambient temperature 30oC and relative humidity 50%