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The effect of admixed material on the ignition temperature of dust layers in hot environments [1]

Fawaz K. Sweis

Department of Chemical Engineering, Faculty of Engineering and Technology, University of Jordan, Amman, Jordan

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Abstract

The ignition temperature of dust layers in a hot environment, has been investigated for several particle sizes, mixtures of coarse and fine dusts of the same material, and mixtures containing partially coarse dusts of limestone. Oil shale and tar sand were used as the industrial materials. Measurement were made in a tube furnace. The results obtained indicated that the ignition temperature is dependent on the particle size and the depth of the layer, and an admixture of coarse dust of 50% of the same material and limestone to fine dust for all the layers of both materials is sufficient to increase the values of the ignition temperature by 0% to 2.1% and 10.9% to 18.4% for mixtures of the same material and mixtures containing limestone, respectively.

Keywords: Dust layer; Ignition temperature; Limestone

1. Introduction

In industries that use or produce combustible dusts, accurate information on its hazards is essential. The general subject of the explosion and fire hazards of dusts and powders is published in such References as [1–5].

In some industrial processes, explosible dust is produced as the main product or as a by-product. Dust layers may accumulate on the internal surfaces of a hot process, for

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example on the internal walls of a dryer. The subsequent ignition of the dust layer may cause a fire, or, if the dust is dispersed, it may cause a dust explosion [5]. Transition from fire to explosion and vice versa may readily occur.

The initiation of dust fires by hot surfaces, or dust deposits in hot environments, is an important hazard. Palmer [1] specifies three types of situation which are likely to arise in practice and give dust fires.

1. Dust deposits or heaps. Typical situations would be thick deposits in a dryer or oven and heated material in a hopper.
2. Dust layers in a heated environment. These may be found as deposits on the walls of dryers, including spray dryers.
3. Dust layers on a hot surface with the other surface of the dust exposed to the atmosphere. Relevant situations include deposits on hot pipes and hot bearings.

Eckhoff [6] in his extensive survey of recent research and development on dust explosions in the process industries provided a discussion on the effect of different types of ignition sources on the ignition processes of dust clouds and dust layers. He suggested that separate theories and mechanisms of ignition should be developed for various categories of ignition sources, such as hot surfaces and electric sparks. For determination of the general ignition and combustion behaviour of dust layers, Siwek [7] suggested that dust deposits must be exposed in pre-tests to the effect of different ignition sources.

Many studies have been carried out to determine the ignition temperature of dust layers. Different types of ignition sources, such as a hot plate [8–10] and a heated environment [5,11] have been used for various configurations of dust layers. These studies demonstrated that values of the ignition temperature decreased as the thickness of the layer increased and the particle size decreased. In addition, the time required for ignition to occur increased with the thickness of the layer. The addition of inert to combustible dusts produced a gradual increase in the ignition temperature [5].

The criterion for indicating an ignition in the tests carried out using a hot plate and a heated environment was the appearance of smouldering combustion [8,9] and flame [5,11] on the upper surface of the dust layer, respectively.

The experimental work presented in this paper was undertaken to extend the range of depths and particle sizes of dust layers studied in hot environments, and to determine the effect of admixed powder on the ignition temperature for mixtures of different particle sizes.

2. Materials

The industrial dusts which were used in this work are Jordanian oil shale and Jordanian tar sand. For each material, samples with a range of particle sizes of d (63 μm $< d <$ 90 μm, 90 μm $< d <$ 125 μm, 125 μm $< d <$ 180 μm and 180 μm $< d <$ 250 μm) were prepared by sieving. The particle sizes of 75.3 μm, 106.1 μm, 150 μm and 212.1 μm were determined as the geometric mean of each range.

3. Materials composition

The materials studied are composed of the following constituents, in percentages by weight. [2]

	Oil shale	Tar sand
Total carbon	23.24	26.74
Organic carbon	19.41	24.11
Sulphur	4.23	4.63
Hydrogen	2.54	3.68
Moisture	2.43	1.9
Volatile	45.31	32.36

4. Equipment and procedure

The experimental values of the ignition temperature were determined for the layers of the tested materials using a horizontal tube furnace. The general arrangement of the furnace is shown in Fig. 1.

The horizontal tube furnace was similar in principle to the Godbert–Greenwald Furnace apparatus. It consisted of a refractory tube, 470 mm long and 40 mm inside diameter, heated externally by an electric winding. The furnace tube was fixed horizontally in a rolled stainless steel case fitted with aluminum end plates. Both ends of the furnace tube were open. The whole case was filled with wool of low thermal mass. Furnace temperatures up to 1200°C were maintained by a temperature controller, governed by a Pt/Pt 13% Rh thermocouple, whose junction was located on the furnace wall at its midpoint. This produced an even temperature distribution at the centre of the tube and extending to a distance of 5 cm on both sides.

The experimental procedure was as follows:

1. The furnace tube was heated and fixed at the desired temperature.
2. A mold of desired dimension was placed on the dust holder. The holder was a long sheet of steel, 30 mm wide and of 5 mm thickness.
3. A quantity of the dust was distributed in the mold to form a loosely packed layer. The mold was then removed and a thin object, such as a flat spatula was used carefully to level the surfaces of the layer to obtain the required dimension [12].
4. The dust holder together with the dust layer were placed in the centre of the furnace tube.
5. Time was measured from placing the sample in the furnace to the observation of flame by using a stopwatch.

Previously, the ignition temperature has been defined as the minimum temperature within the dust layer at which flame develops and is observed [5,11]. In practice, using a

[2] Prepared by Natural Resources Authority, Amman, Jordan.

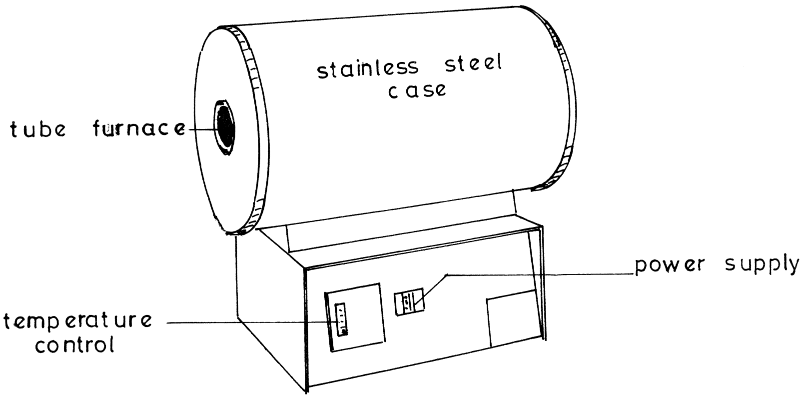

Fig. 1. The tube furnace apparatus.

Godbert–Greenwald Furnace apparatus and a horizontal tube furnace, the temperature of the dust layer when flame appeared was the same as the wall temperature of the furnace. In this work, the same criterion of ignition was employed.

Successive test trials were made at higher or lower furnace temperatures until a minimum ignition temperature was obtained for the dust layer. With each layer and after each ignition, the temperature of the furnace was lowered by 10°C until a temperature was reached at which ignition did not take place in at least three repeated tests. The duration of the test was four minutes, unless ignition occurred sooner. Freshly prepared samples were used for each test.

The results obtained from the test are directly applicable to situations where dusts may be stored under warm conditions, or may be processed for considerable periods of time in warm plant, such as in drying ovens.

5. Dimension of the layers

In the previous work [11], it was shown that there was no great effect between the rectangular and cylindrical shapes of layers on the ignition temperature.

The rectangular shape resembles to a high degree the accumulation of dusts on the surfaces of industrial units, and also its required dimension can be maintained exactly throughout the test procedure.

It was then decided to use the rectangular shape throughout this work with the following dimensions:

Layer No. 1: 50 mm long, 20 mm wide and 2 mm depth
Layer No. 2: 50 mm long, 20 mm wide and 5 mm depth
Layer No. 3: 50 mm long, 20 mm wide and 8 mm depth

The chosen depths cover those encountered in practical situations.

6. Results and discussion

6.1. Effect of particle size on ignition temperature

Figs. 2 and 3 illustrate the effect of particle size (μm) on the ignition temperature (°C) for the three specified layers of oil shale and tar sand. Many tests were carried out for each sample. The results are presented as curves through points representing the lowest temperature at which each material of the corresponding particle size and layer thickness was ignited with flame.

The results demonstrate that the ignition temperature increased with the particle size of the material. Values of the ignition temperature obtained with a specific particle size were higher with layer No.1 than those obtained with the other two layers. By comparing the figures, the results also reveal, as before [11], that the values of the ignition temperature obtained with oil shale were higher than those obtained with tar sand, whereas the rate of increase with particle size was higher for tar sand than that for oil shale.

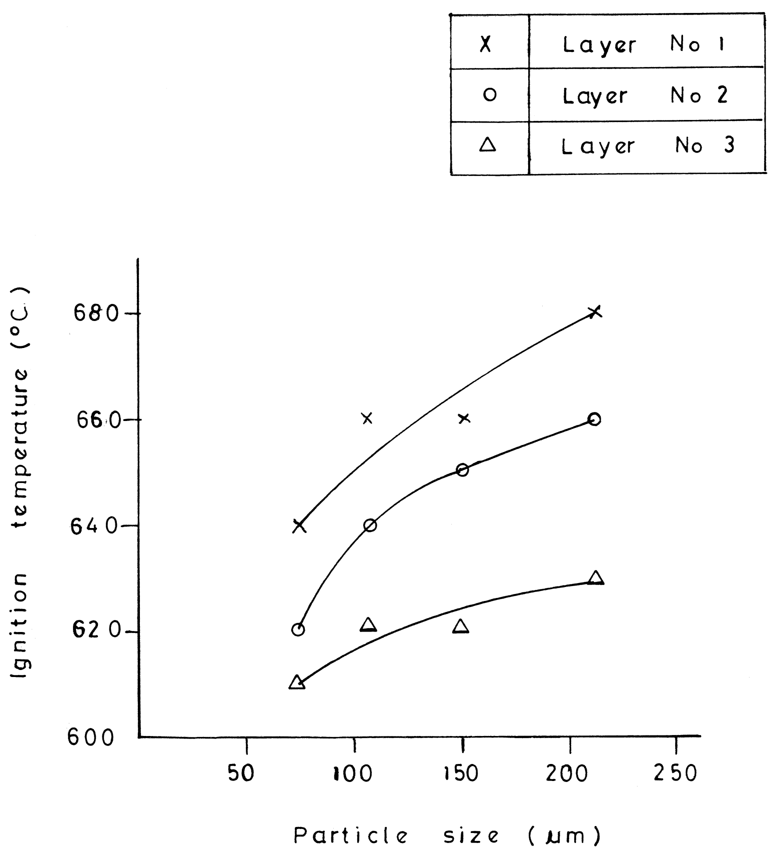

Fig. 2. The variation of the ignition temperature with particle size for all the layers of oil shale.

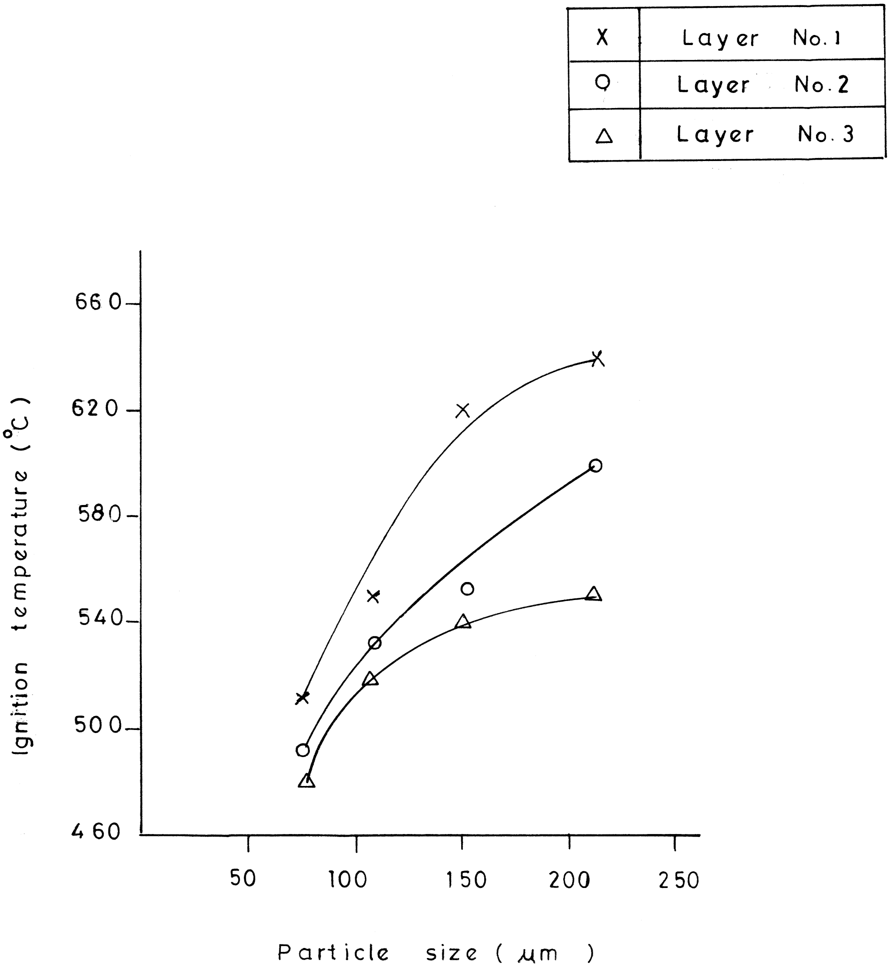

Fig. 3. The variation of the ignition temperature with particle size for all the layers of tar sand.

Table 1 lists values of the ignition temperature together with the time required for ignition for all the particle sizes of the layers studied. The table indicates that values of the time required for ignition decreased as the particle size of each layer increased and the depth of the layer decreased. In general, values of the time required for ignition of oil shale is lower than that needed for tar sand.

6.2. Effect of mixtures of particle sizes on ignition temperature

In industrial situations, deposits of dusts on surfaces of the process units are not usually of uniform particle size, and it is necessary to know the influence of the particle size distribution of layers on the values of the ignition temperature.

For the three specified layers of oil shale and tar sand, mixtures of particle sizes of 75.3 μm and 212.1 μm were prepared containing different weight percentages of these

Table 1
Values of the ignition temperature and the time required for ignition for all the layers

Material	Layer no.	Particle size (μm)	Ignition temperature (°C)	Time (s)
Oil shale	1	75.3	640	63
		106.1	660	51
		150	660	27
		212.1	680	10
	2	75.3	620	125
		106.1	640	120
		150	650	90
		212.1	660	57
	3	75.3	610	165
		106.1	620	146
		150	620	115
		212.1	630	87
Tar sand	1	75.3	510	195
		106.1	550	101
		150	620	87
		212.1	640	47
	2	75.3	490	202
		106.1	530	188
		150	550	180
		212.1	600	173
	3	75.3	480	225
		106.1	520	210
		150	540	190
		212.1	550	185

sizes, and the ignition temperature of the mixtures determined. The particle sizes of 75.3 μm and 212.1 μm had produced the lowest and highest values of the ignition temperature for each layer of both materials, respectively. Values obtained with 100% coarse and fine dusts of each material are also plotted. The results are shown as solid lines in Figs. 4 and 5.

The results indicate that as the percent by weight of large particles increased from 0% to 50%, the ignition temperature was almost constant for all the layers of both materials. With a further increase in the percent by weight of large particles, values of the ignition temperature increased moderately and sharply for all the layers of oil shale and tar sand, respectively. The figures also show that the ignition temperature of layers falls between the ignition temperatures of the pure coarse and fine dusts of each separate material.

Since the ignition temperature of fine particle size can be elevated by adding proportions of coarse particle size of the same material, it would be of value to compare the results obtained with those for mixtures containing the same coarse particle size (212.1 μm) of another admixed inert material such as limestone (95% by weight calcium carbonate) [13]. The results are shown as dashed curves in Figs. 4 and 5, and demonstrate that values of the ignition temperature and its rate of increase obtained with mixtures containing limestone were higher than those obtained with mixtures of the same material.

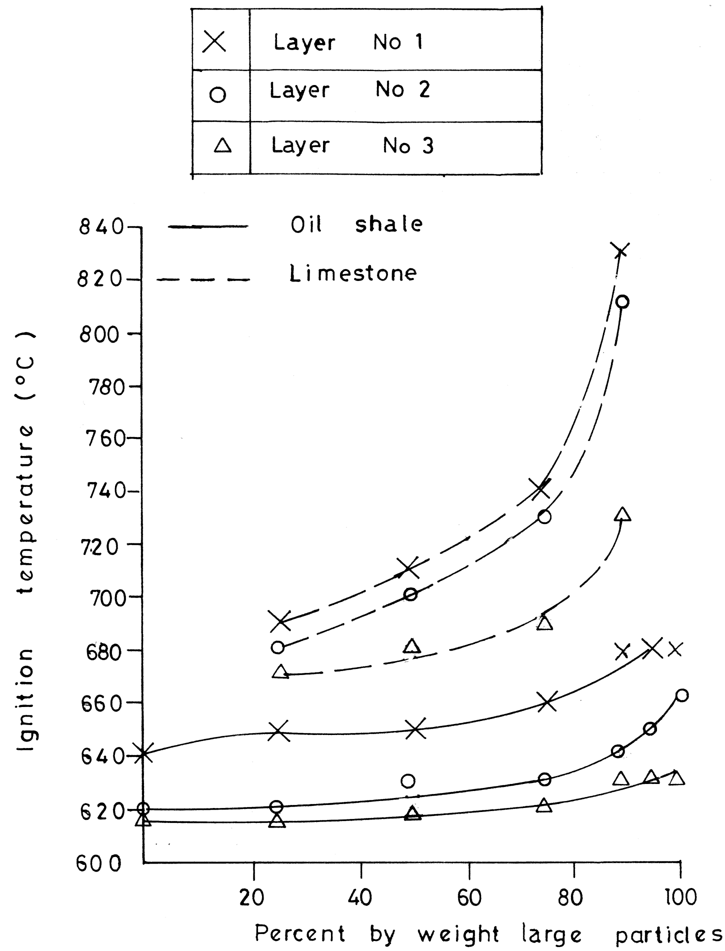

Fig. 4. The variation of the ignition temperature with percent weight of coarse dusts and limestone in the mixtures of oil shale.

Table 2 lists all the values of the ignition temperature and the time required for ignition for all the layers of mixed dusts. The table indicates that the time required for ignition increased with the percent by weight of large particles for any layer. More data are needed to predict the variation of ignition temperature with time for layers of mixed materials.

The most important result of these tests (Figs. 4 and 5) is the highly non-linear relationship between the composition of the layer mixture (percent by weight of large particles) and the value of the ignition temperature. Thus, for example, an admixture of 50% by weight of coarse with fine particles increases the ignition temperature for all the layers of pure fine oil shale by 1.6%. For mixtures containing oil shale and limestone, the increase in the ignition temperature was 10.9%, 12.9% and 11.5% for layers 1, 2 and

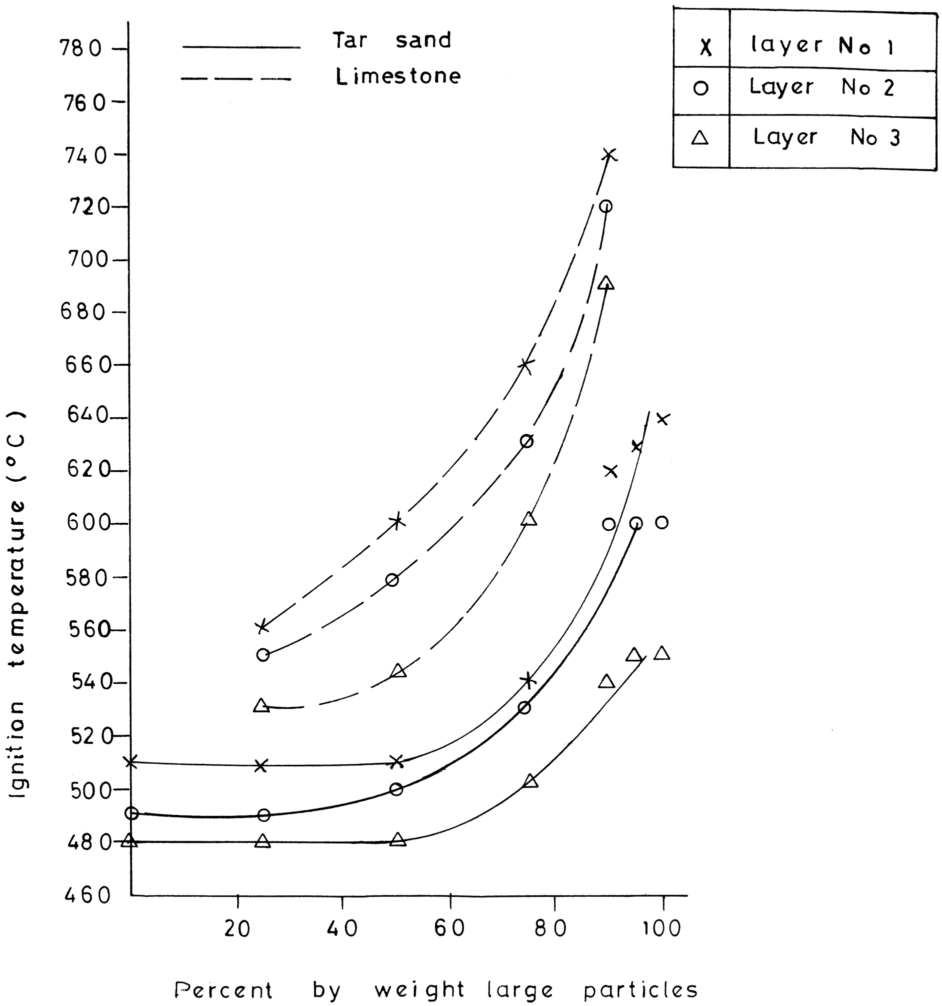

Fig. 5. The variation of the ignition temperature with percent weight of coarse dusts and limestone in the mixtures of tar sand.

3, respectively. Whereas, for mixtures containing fine and coarse particles of tar sand, the increase in the ignition temperature for pure fine tar sand was 0%, 2.1% and 0% for layers 1, 2 and 3, respectively, and for mixtures containing tar sand and limestone, the increase was 17.7%, 18.4% and 12.5% for the same layers. For these particles the ratio of particle diameters of coarse to fine was of the order of 3 to 1. Also, the percentage increase in the values of the ignition temperature for any type of admixed material decreased as the thickness of the layer increased.

The ignition of a dust deposit in a hot environment depends upon the balance between the heat generation rates produced by a reaction of the dust with air and the heat loss rates arising from cooling of the dust to its surroundings. The heat generation

Table 2
Values of the ignition temperature and the time required for ignition for layers of mixed dusts

	Layer no.	Particle size (μm)	materials in mixture	Weight percentages						
	1	75.3	Oil shale	0	5	10	25	50	75	100
		212.1	Oil shale	100	95	90	75	50	25	0
Ignition temperature, °C				680	680	680	660	650	650	640
Time, s				10	12	25	30	35	47	63
	1	75.3	Oil shale		5	10	25	50	75	
		212.1	Limestone		95	90	75	50	25	
Ignition temperature, °C					*	830	740	710	690	
Time, s					*	70	105	120	130	
	2	75.3	Oil shale	0	5	10	25	50	75	100
		212.1	Oil shale	100	95	90	75	50	25	0
Ignition temperature, °C				660	650	640	630	630	620	620
Time, s				57	80	103	120	123	130	125
	2	75.3	Oil shale		5	10	25	50	75	
		212.1	Limestone		95	90	75	50	25	
Ignition temperature, °C					*	810	730	700	680	
Time, s					*	77	110	130	135	
	3	75.3	Oil Shale	0	5	10	25	50	75	100
		212.1	Oil Shale	100	95	90	75	50	25	0
Ignition temperature, °C				630	630	630	620	620	620	610
Time, s				87	106	120	127	132	155	165
	3	75.3	Oil Shale		5	10	25	50	75	
		212.1	Limestone		95	90	75	50	25	
Ignition temperature, °C					*	730	690	680	670	
Time, s					*	135	145	157	181	
	1	75.3	Tar sand	0	5	10	25	50	75	100
		212.1	Tar sand	100	95	90	75	50	25	0
Ignition temperature, °C				640	630	620	540	510	510	510
Time, s				47	152	170	176	190	200	195
	1	75.3	Tar sand		5	10	25	50	75	
		212.1	Limestone		95	90	75	50	25	
Ignition temperature, °C					*	740	660	600	560	
Time, s					*	185	190	200	205	
	2	75.3	Tar sand	0	5	10	25	50	75	100
		212.1	Tar sand	100	95	90	75	50	25	0
Ignition temperature, °C				600	600	600	530	500	490	490
Time, s				173	163	171	185	193	210	202
	2	75.3	Tar sand		5	10	25	50	75	
		212.1	Limestone		95	90	75	50	25	
Ignition temperature, °C					*	720	630	580	550	
Time, s					*	180	195	210	210	
	3	75.3	Tar sand	0	5	10	25	50	75	100
		212.1	Tar sand	100	95	90	75	50	25	0
Ignition temperature, °C				550	550	540	500	480	480	480
Time, s				185	173	178	200	214	230	225
	3	75.3	Tar sand		5	10	25	50	75	
		212.1	Limestone		95	90	75	50	25	
Ignition temperature, °C					*	690	600	540	530	
Time, s					*	190	200	220	230	

* = No burning.

rates and heat loss rates might be expected to depend on many variables, such as types, composition and particle size of the dust, geometry and thickness of the layer, chemical structure, oxygen available and equipment factors. Any treatment is likely to be complex, but as more data becomes available the situation will improve.

7. Conclusions

The experimental values presented for the ignition temperature of mixed dust layers provide the parameter which is of most use for assessing the hazards of dust fires and for developing safety systems.

Studies of the ignition of layers of oil shale and tar sand in hot environments have confirmed that the depth of the layer and the particle size are important factors affecting the ignition temperature.

The results show that the ignition temperature of dust layers can be elevated by adding different percentages of coarse particles of the combustible material itself or limestone. The ignition temperature for layers contain mixed dusts was found to depend on the depth of layer, type and weight percentage of admixed material and its chemical reactivity. Limestone was found to influence the values of the ignition temperature for the mixtures of oil shale and tar sand more than the coarse particle size of the material itself. A 50% of admixed limestone increased the ignition temperature for pure fine oil shale by 10.9%, 12.9% and 11.5% for layers of 2 mm, 5 mm and 8 mm depths, respectively. The corresponding increase for pure fine tar sand was higher, i.e., up to 17.7%, 18.4% and 12.5%.

Values of the ignition temperature reported did not include a safety factor. In applying these values to industrial situations, a safety factor of at least 75°C below that required for the ignition of the dust must be used [1].

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