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Incineration of Non-radioactive Simulated Waste

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ABSTRACT

Key words : Incineration, Non radioactive simulated waste, Environmental impacts

An advanced controlled air incinerator has been investigated, developed and put into successful operation for both non radioactive simulated and other combustible solid wastes. Engineering efforts concentrated on providing an incinerator which emitted a clean, easily treartable off-gas and which produced minimum amounts of secondary waste. Feed material is fed by gravity into the gas reactor without shredding or other pretreatment. The temperature of the waste is gradually increased in a reduced oxygen atmosphere as the resulting products are introduced into the combustion chamber. Steady burning is thus accomplished under easily controlled excess air conditions with the off-gas then passing through a simple dry cleaning-up system. Experimental studies showed that, at lower temperature, CO_2, and CH_4 contents in gas reactor effluent increase by the increase of glowing bed temperature, while H_2O, H_2 and CO decrease. It was proved that, a burn- out efficiency (for ash residues) and a volume reduction factor appeared to be better than 95.5% and 98%, respectively. Moreover, high temperature permits increased volumes of incinerated material and results in increased gasification products. It was also found that 8% by weight of ashes are separated by flue gas cleaning system as it has chemical and size uniformity. This high incineration efficiency has been obtained through automated control and optimization of process variables like temperature of the glowing bed and the oxygen feed rate to the gas reactor.

INTRODUCTION

A generator of hazardous contaminated waste has several disposal options. All of which promise to be come increasingly expensive in the future. Long term storage and landfills have inherent liabilities and steady increasing costs, as available sites diminish and regulations drive operating costs. Because of the considerable specific volumes, and other physical and chemical qualities, as well as the contaminated wastes are not appropriate for final disposal, volume reduction using controlled incineration process would be highly desirable, as it is often considered to be ultimate disposal approach to contaminated wastes. The potential advantages of controlled incineration are varied. The primary advantage results from volume reduction of approximately 90%, as incineration is employed to minimize the stored waste volumes, and to convert the largest portion of the contaminated waste into chemically inert form (ash). The produced ash is much easier to be handled and disposed than originally generated waste in nuclear research centers, nuclear facilities, and hospitals as well. In addition to volume reduction, there is also detoxification of contaminated materials, as it can be broken into constituents parts composed mainly of carbon dioxide, CO_2 and water vapor, H_2O. Numerous incineration technologies have been developed [(1)] to incinerate a vast array of contaminated wastes. Many of these techniques are employed at general purpose permanent facilities, regional incinerators that serve customers by accepting and destroying any appropriate waste. The thermal treatment of wastes by incineration is a process involving many mechanisms and reaction courses not yet sufficiently investigated [(2)]. In reducing waste volume and destroying potentially contaminated waste, air pollution is an unavoidable by-product. Nearly complete destruction of hazardous constituents by combustion is required, however, the trace quantities of incomplete combustion especially dioxin and furans are not currently regulated by Egypt and many countries. Further high destruction efficiencies require high temperature and increased turbulence. Both of these promote increased oxides of nitrogen, which are acid rain precursors. Oxidation of fuel nitrogen, sulphur and halogens produce additional nitrogen oxides, as well as sulphur oxides, and acid gases. Non combustibles such as trace metals are all potentially emitted with fly ash. With these potential classes of pollutants, trace hazardous organic, acid gases, trace heavy metals, and the fly ash, the air pollution control strategy selected must have the potential for multipollutants control to minimize costly retrofit or upgrading to meet future regulations. A special attention must be given to bag filter and cyclone separator dusts because of their high quantities and contents of heavy metals such as copper, zinc, cadmium, cobalt and other organic pollutants [(3)].

Experimental Work and Process Chemistry

The Low Active Waste Incinerator(LAWI) demonstration facility of the latest design is the research tool available to the Nuclear Research Center (NRC), where scientific investigation of contaminated waste incineration and flue gas cleaning may be conducted . The objective of this investigation work is to develop an ecologically solid waste incineration process combined to the control of problems arising from pollutants present in all streams, and to concentrate pollutants residues from flue gas cleaning to make them suitable for proper disposal [(4)]. Prior to conducting the present investigation several modifications have been recommended and carried out as follows :

- The redesign of the throat of the loading station to allow feeding of two bags together without operation problems.

- Replacement of the manual flat valve of loading station by motorized valve to improve performance.
- Installation of sampling station for flue gas as recommended by Environment Protection Agency(EPA)
- Replacement of all manual valves by electro-mechanical valves for easy operation
-Installation of pressure transducers for pitot tubes to simplify flow measuring of injected air , gas reactor product gases , and flue gas;
-Modification of basic software of data acquisition system;
-Installation of sampling points of gas reactor product gas and flue gas;
-Installation of temperature controller to control the glowing bed temperature;
-Cancellation of Lamada sensor used to control air feed to the combustion chamber due to created process disturbance.

The incinerator is schematically presented in Fig.(1). The main parts are :
Glove box and loading station , Gas reactor, Combustion chamber, Air mixing chamber, Cyclone separator, Filter group which includes : Bag filters, and HEPA filters, Valves, fittings, and piping systems, Burner and gas feeding system, Process control and instrumentation, Data acquisition system . To assure a good performance, as well as accurate thermohydraulic data collection , LAWI is equipped with process control and safety systems . The operating switches and control of various electro mechanical components (valves, burner,, exhaust blower and fresh air blower) are located on the control panel, as the entire installation can be operated and controlled easily by only two employees. Moreover, construction allows for very fast start up and shut down .

The following key design and operational objectives were set and subsequently met.
- The system was designed for 15 Kg/hr feed rate suitable for most applications. However, inherent stability or operational characteristics should not prevent sizing for much higher or lower feed levels.
- A simple gravity feed was desired which allow the introduction of waste into gas reactor without sorting, shredding, metal separation or other pretreatment.
- A high quality uniform off-gas production, as dry gas treatment system could be used without need for wet scrubbing.
- The incinerator must accept a wide variety of feed materials.
- normal operation must be economical with no fuel requirement after startup.
- A system based on easily controlled combustion reactions and minimum bad impact

Process Description

The gas reactor has to be filled completely with simulated non-radioactive waste via glove box, without shredding or pretreatment. During operation, there is a positive temperature gradient [5] in the waste column, as temperature increases from near room temperature at the top of waste column to about 800 °C around the movable grate (Fig. 2). By addition of under-stoichiometric amount of air, the waste is dried, decomposed, and then gasified in distinct zones on the waste column. The gas consisting of CO, CO_2, H_2, water vapor and traces of methane is produced. The CO, H_2 and the methane are oxidized by addition of secondary air into the combustion chamber. Also pyrolysis coke and tar like substances are cracked in this chamber at about 1000 °C.

Ashes and coke are falling through the grate to the bottom of the gas reactor, where it may be burned out by addition of secondary air.

To meet the requirement of Clean Air Act, and the Nuclear Laws, and Ordinances, an efficient off-gas purification system is necessary. The off-gas is cooled down to about 200 °C in the mixing chamber by mixing with fresh air before it pass through the cyclone separator and then filtered by using filter group which consists of a self cleaning bag-filters and high efficiency particulate absolute (HEPA) filters. The purified gas is finally sucked by the exhaust blower and emitted to the environment via the stack.

Ashes are removed periodically from gas reactor, combustion chamber, cyclone separator and bag-filters into 40L steel drums to be conditioned by any of the proven conditioning techniques.

Schedule, Feed stock and Operating Conditions

Prior to operating the incinerator, each component and subsystem of the facility was tested. The checkouts requirements included operating the control valves, blowers, controllers and bag house pulse cleaning system. During this period, the instrumentation was calibrated.

Various experimental runs of 6 hours continuous operating time each, for the incineration of two types of wastes were performed under the following:

(1). Schedule

Six experimental campaigns of 3 to 4 months were carried out with LAWI during 1995 and 1996 as approximately 1100 Kg of non-radioactive simulated waste was incinerated.

(2). Stock materials

Table I lists the composition of the typical incinerable waste used in this experimental work, as account must be taken of waste characteristics such as calorific value, the physical and chemical state.

Non-radioactive traces containing Co, Mn, Zn and Fe are added to the feed materials in the mixed waste in various experimental campaigns.

(3). Operating conditions

Table II lists the important operating parameters for the particular experimentation.

4. Measured and calculated data.

Various experimental campaigns have been carried out to measure and determine the following data for the incinerated waste :

Description	**Method used**
Gasification rate at different glowing bed temperature	Extent of reaction concept
Composition of H_2, CO, CO_2 and N_2 in the gas reactor product gases.	Analysis by Orsat gas analyzer model GAG 120
Composition of H_2O in the gas reactor product gases	Condensation
Thermohydraulic data	
Air and flue gases flow rates	Pitot tube
Pressures	pressure gauges
Temperatures	Thermocouple
Composition of exhaust gas	Computerized Gas Analyzer model MSI 200

Process Chemistry

The thermal treatment of waste by a controlled air incineration technique is a process involving many mechanisms and reaction courses not yet sufficiently investigated.

The controlled air incineration is a simple process, being gasification of waste material is essentially a 2 steps endothermic process, as chemical compounds that form a part of waste are gasified to form ultimately simple gaseous products. The gasification efficiency is quite dependent on:

- The glowing bed temperature
- The quantity of air injected to the system as air flow is limited to about 30-50 percent of the air required for complete combustion [6]
- The partial pressure of gaseous products.

For the incinerated waste, the first step endothermic reaction occurring as follows:

$$1/n\,(C_6H_{10}O_5)_n + 1/2\,O_2 \rightarrow 6\,CO + 5\,H_2$$

$$1/n\,(CH_2\text{-}CH_2)_n + O_2 \rightarrow 2\,CO + 2\,H_2$$

$$1/n\,(C_5H_8)_n + 5/2\,O_2 \rightarrow 5\,CO + 4\,H_2$$

Unfortunately, the cited reaction is idealized. In reality, cellulosic fibers are mainly producing high boiling organic products and elemental carbon. In step 2, the elemental solid carbon resulting from step 1 undergoes conversion to carbon monoxide, and hydrogen via carbon and water vapor reaction.

$$C + H_2O = CO + H_2$$

Also, additional side reactions may be occurred as follows:

$$CO_2 + H_2 = CO + H_2O$$

$$CH_4 + H_2O = CO + 3\,H_2$$

To provide energy necessary for drying, decomposition and gasification and to sustain thermal destruction, group of exothermic reactions important to the system must be secured as follows:

$$2\,CO + 2\,H_2 \rightarrow CH_4 + CO_2$$

$$2\,CO \rightarrow CO_2 + C$$

As the analysis of gas reactor product gases arising from working campaigns supports these reactions.

RESULTS AND DISCUSSION

During the first experiments under automatic control approximately 900 Kg of wood (cellulose) waste was incinerated. Adjustments of the controllers settings and measuring instruments as required were satisfactory.

It was possible to burn waste composition ranging from 100% cellulose to the non-radioactive simulated waste with characteristics as shown in Table (I) without operational problems.

It was proven that the design of the incinerator allows for very fast startup periods of 0.5 hour as shown in Fig. (3) for the non radioactive simulated waste at different operating conditions.

Quality and Yield Products.

The performance and experimental results obtained from processing feed stocks of the non-radioactive wastes are described below.

Gasification Product Gases

Figure (4) shows the relationship between the glowing bed temperature and the gasification rate, as high temperatures permit increased volumes of incinerated materials and produced gases per unit time for both types of wastes. Table (IV) shows the average composition of gasification products, as CO, CO_2, and hydrogen volume percent were determined by Orsat Gas Analyzer (model GAG 120) while water vapor content was determined by condensation. Experimental results proved that, at lower temperature, the CO_2, and CH_4 contents increase, while the H_2O, H_2, and CO contents decrease. This results in a small change of the calorific value. Figures (5) and (6) show the influence of the glowing bed temperature on the composition of gas reactor product gases. Based on results reported previously [7,8], the system has to be operated at relatively medium temperature, as this has a high importance for the destruction of dioxin (PCDD), and furans (PCDF) formed in the presence of chlorinated compounds.

Volume Reduction

Volume reductions of solid waste were found to be substantially the same for each of the different waste tested. An average waste volume reduction factor of 98% was observed (without regarding further reduction by compressing and conditioning of the ashes). These high values are achieved due to the good combustion capability of the processed wastes. Figure (7) illustrates the reduction factor for different working campaigns.

Burn-out Efficiency

An average burn-out efficiency of 95.6%, for solid residues (bottom and fly ashes) were observed for the non-radioactive simulated wastes, while the unburned materials in the flue gas were close to zero. These high values of burn-out efficiency for bottom ashes were achieved by injecting air to the bottom ash before unloading at relatively low temperature to assure carbon burn-out. The high value of burn-out of fly ash and flue gas were obtained by optimizing the operating temperature and excess air supply in the combustion chamber. Table (III) shows the values of burn-out efficiency obtained for the different working campaigns for the both types of wastes

Environmental Effects

It was proven that the potentially harmful constituents contained in the flue gas are lower than the values specified as standard limits for incinerator exhaust gas in FRG. Thus it was ascertained that system is essentially free of pollution.

Exhaust Gas

It was found that the concentration of CO, NO_x, SO_x, and unburned carbon particulate which are determined by computerized gas analyzer model, were found less than the values specified for incinerator exhaust gas as shown in Table(V). Sampling with an EPA method 5 stack sampler of exhaust gas emitted to the environment via stack showed that only trace amounts of particulate were captured on the fiberglass filter and the aqueous solutions. This indicated that the bag filters and HEPA filters are performing efficiently. Results indicated that the concentration of metals Zn, CO, Mn and Fe in the scrub solutions of the bubblers were below the detection limit. The statistical analysis of the data of the exhaust gas composition obtained from the incineration of both wastes are shown in Table (VI). Experimental results impressively show that the sulpher and nitrogen are not distributed homogeneously in the solid waste , but SO_x and NO_x are detected as discrete events . The example of the two days of measurements is to show the doubtful nature of discontinuous random sample measurements.

Residues

It was proven that the fly ash obtained from the incinerator flue gas cleaning system (cyclone, bag filters) for both types of waste has chemical and size uniformity which allow it to be conditioned and stabilized by any of the accepted and proven techniques [5,9,10]. In most cases, the bottom ash has the same uniformity, as it may contain some coarse clinkers and unburned pieces due to the lack of oxygen and incomplete combustion. The X-ray qualitative analysis of bottom and fly ash powder using Scanning Electron Microscope, shows that the chemical constituents and heavy metals are partially distributed between the fly and bottom ash.

About 8% (by weight) of the ashes was collected in the gas purification system. No ashes were found behind the bag filters.

CONCLUSIONS

A summary of the aforementioned brings about the specified conclusions .

1. The low active waste incinerator (LAWI) with the latest modified design is proven as a powerful tool for various applications as complete combustion, and high volume reduction factor are guaranteed.
2. The incinerator can be easily controlled, mainly by controlling primary air fed to the gas reactor.
3. The CO_2 and CH_4 contents in gas reactor effluent increase at lower temperature glowing bed, while the H_2O, H_2 and CO contents decrease.
4. It was proven that the potentially harmful emissions in the flue gas are lower than the values specified as standard limits for incinerator exhaust gas.
5. It was found that the fly ash obtained from the incinerator flue gas cleaning system is characterized by chemical and size uniformity and can be easily stabilized

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Table I. Incinerable Waste Characteristics *

Average chemical composition	
Cellulose (wood, paper, cardboard, cotton, and textile	33 %
Plastics (non-halogenated)	45 %
Plastics(Halogenated)	3 % max.
Rubber	3 %
Humidity	16 % max.
Physical properties	
Average density	400 kg / m^3
Average heating value	12,000 kJ / kg

Table II Important operating conditions

Waste processed	11-15 kg / hr
Glowing bed temperature	650 - 800 ° C
Combustion chamber temperature	1000 - 1100 ° C
Flue gas temperature after mixing chamber	200 ° C
Air consumption in gasification	Approx. 15 Nm^3 /hr

Table III . Burn out efficiency

Glowing bed temperature, ° C	**Burn out efficiency**		
	Bottom ash	Fly ash	Flue gas
650	95.2	95.9	> 99.9
700	95.3	95.9	> 99.9
800	95.5	95.9	> 99.9

Table IV . Gas Reactor Effluent Composition

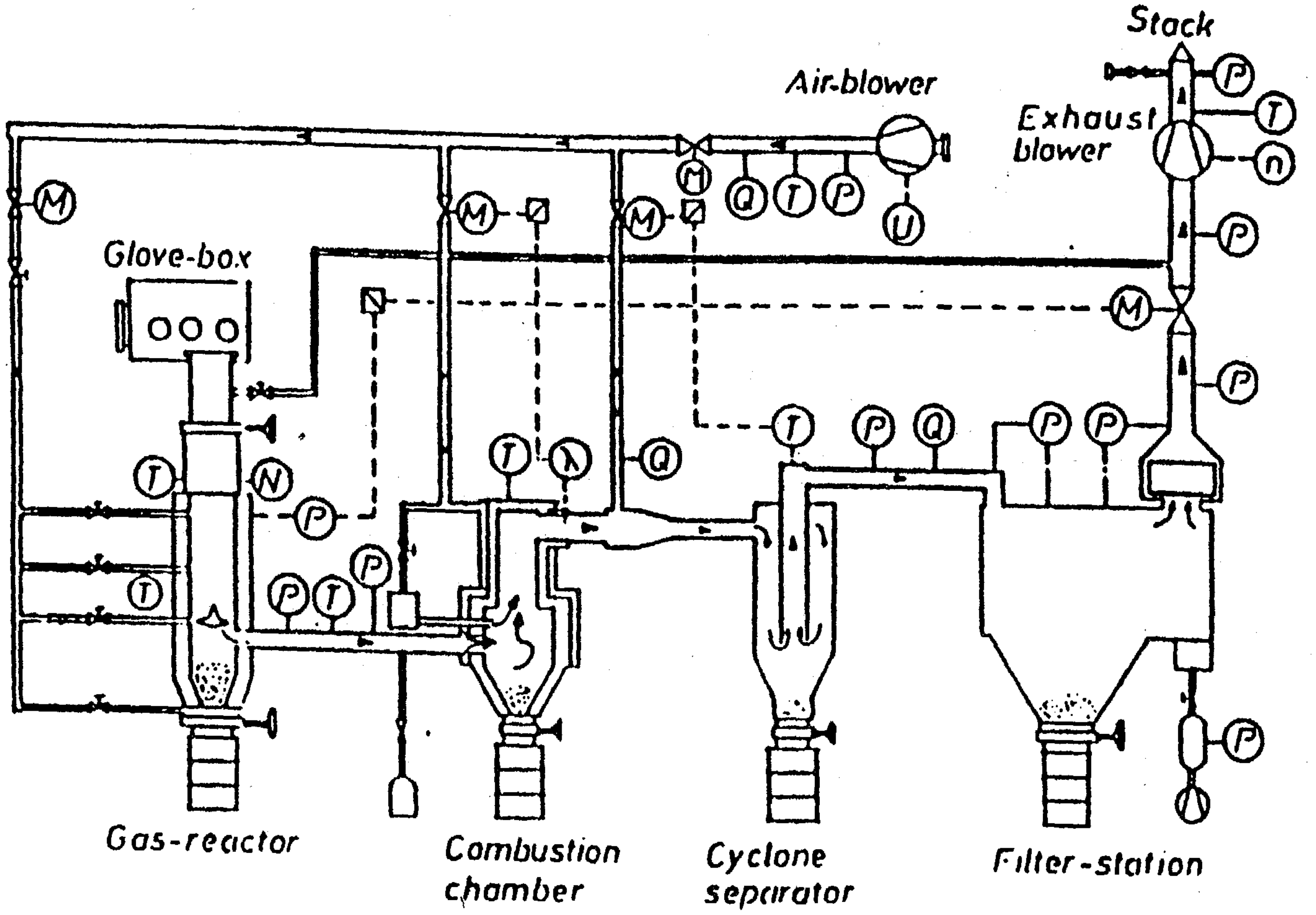
Constituent	Average composition, %
H_2	20.2
O_2	0.0
CO	19.2
CO_2	8.5
CH_4	4.1
H_2O	11.5
N_2	36.6

Table V Exhaust Gas Composition

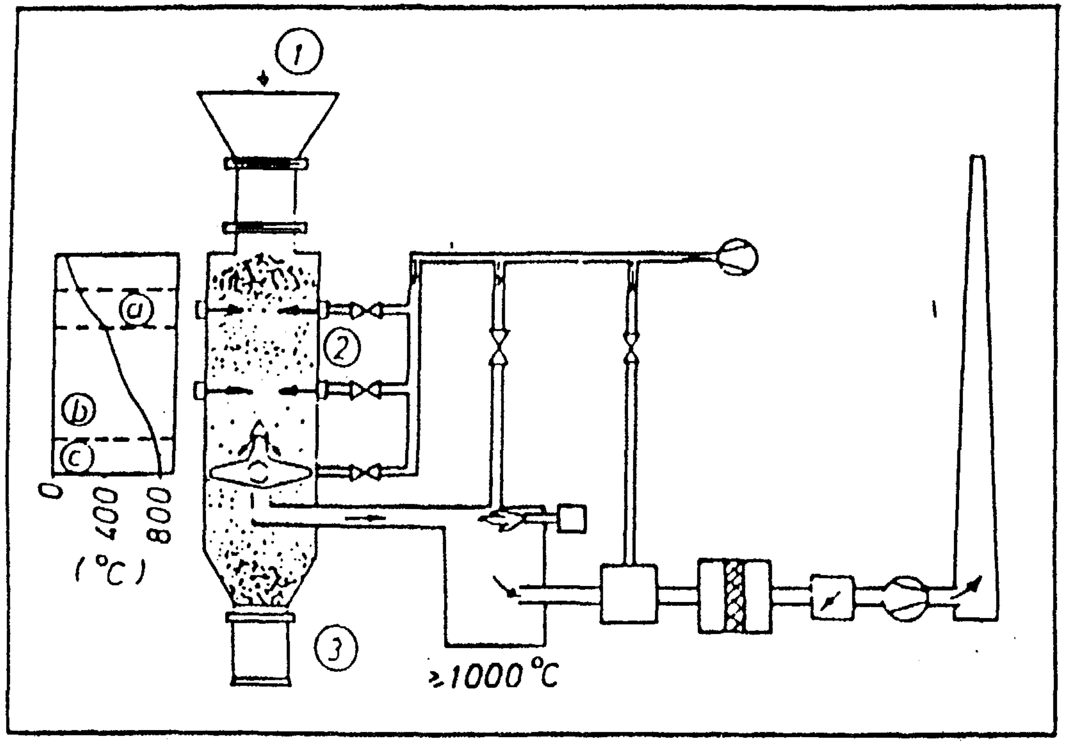
Constituent	Composition, %
O_2	13.3
CO	60 ppm max.
CO_2	6.5 - 8.3
NO_x	55 ppm max.
SO_x	0-35 ppm
Dioxins(PCDD)	not detected
Furans(PCDF)	not detected
Soot	Soot No. 0-1 acc. to Bachardh .

Table VI Statistical Analysis for Exhaust Gas Composition

Parameter	Constituent				
	CO	CO_2	NO x	SO x	O_2
No. of samples	29	31	34	36	37
Minimum value	4 ppm	0.06	0 ppm	0 ppm	0.133
Maximum value	60 ppm	0.08	55 ppm	35 ppm	0.16
Average value	27 ppm	0.068	32 ppm	11 ppm	0.1512
Standard deviation	20.1	0.93	19.15	12.9	0.788



Figure(1). Schematic LAWI flow sheet.



(1)	Material feed	(a)	Drying
(2)	Gas reactor	(b)	Degassing
(3)	Ash discharge	(c)	Gasification

Figure (2) The Julich thermoprocess, operating principle.

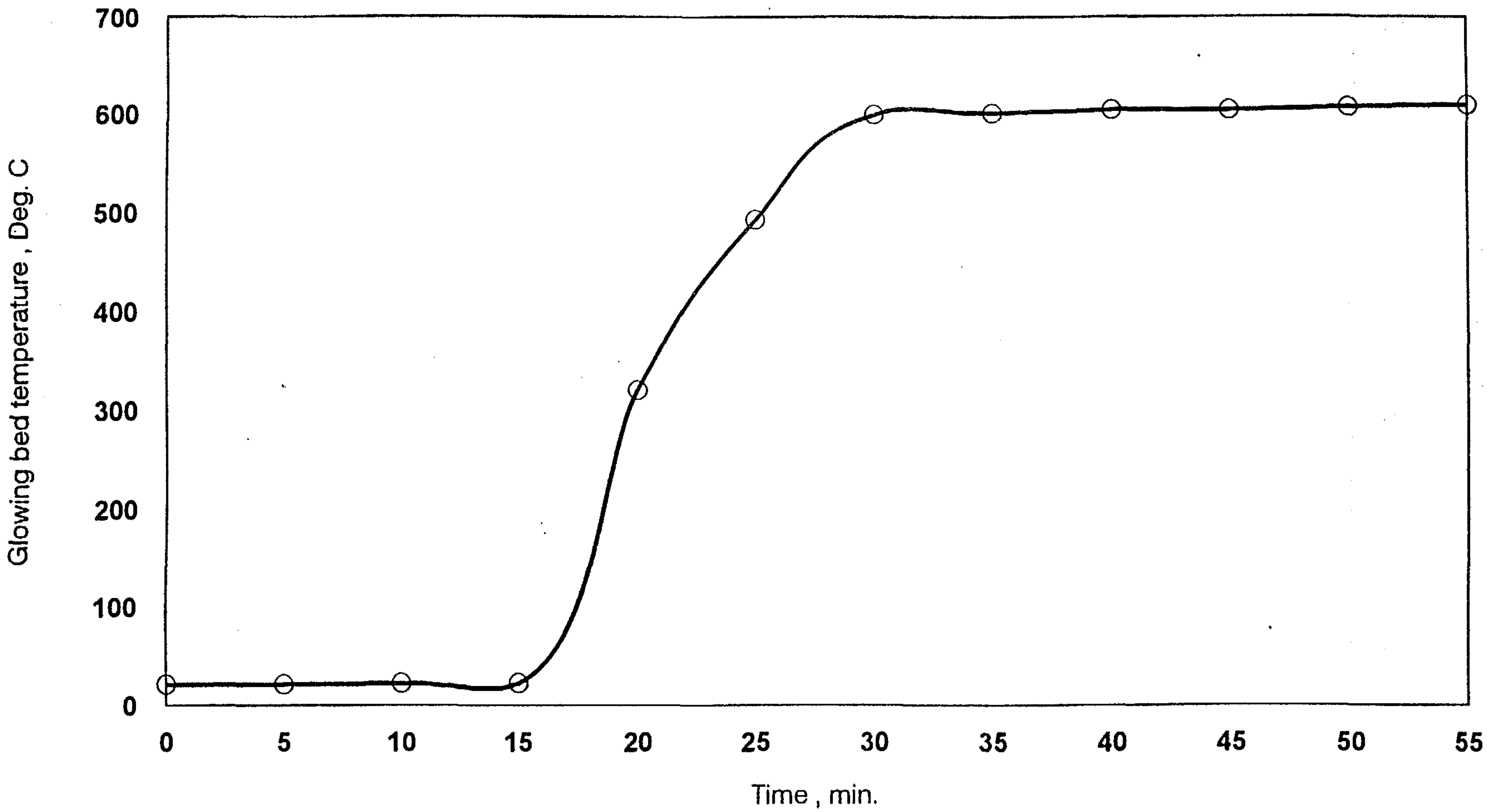


Fig. 3 . Glowing bed temperature versus time at start-up

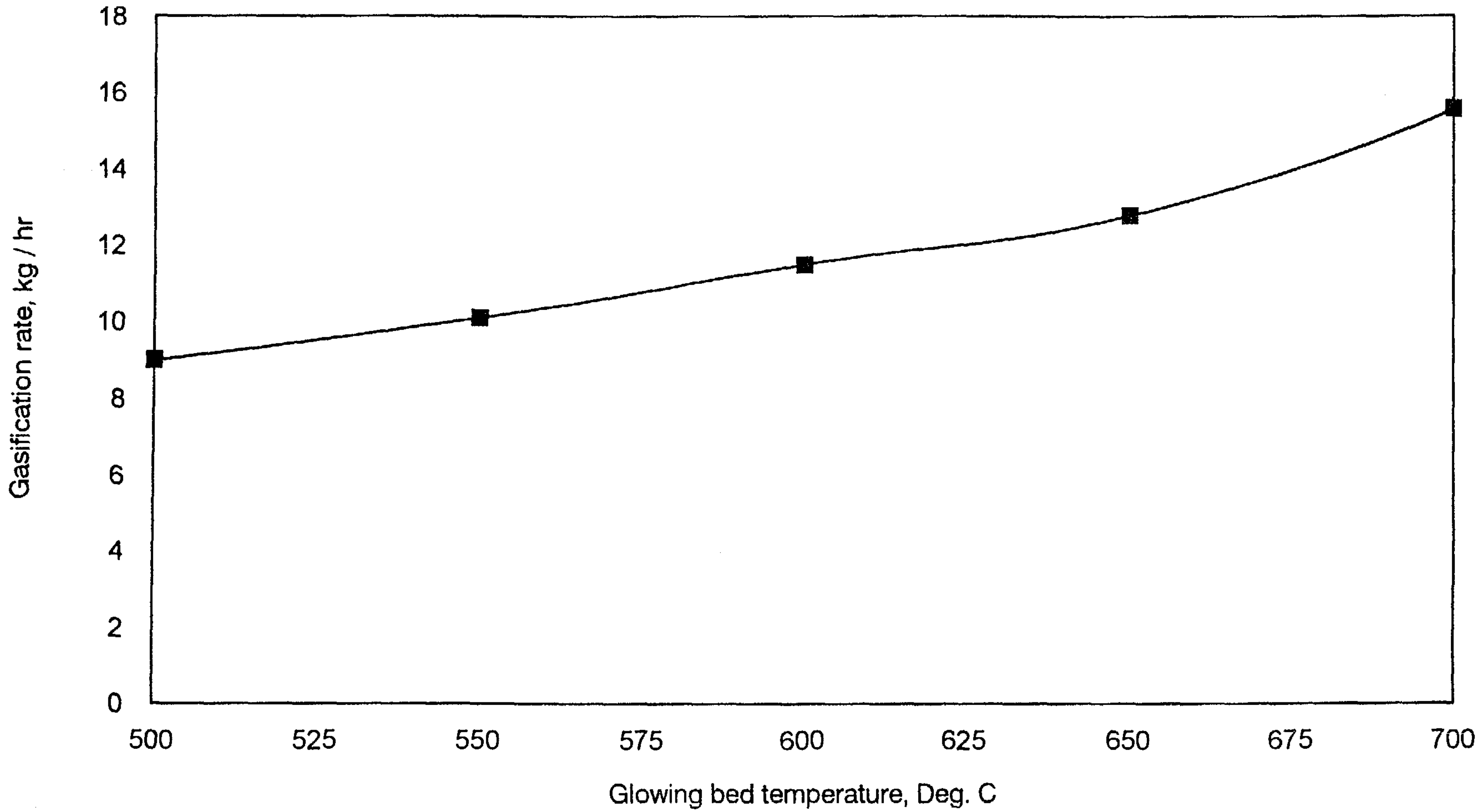


Fig. 4. Influence of glowing bed temperature on gasification rate

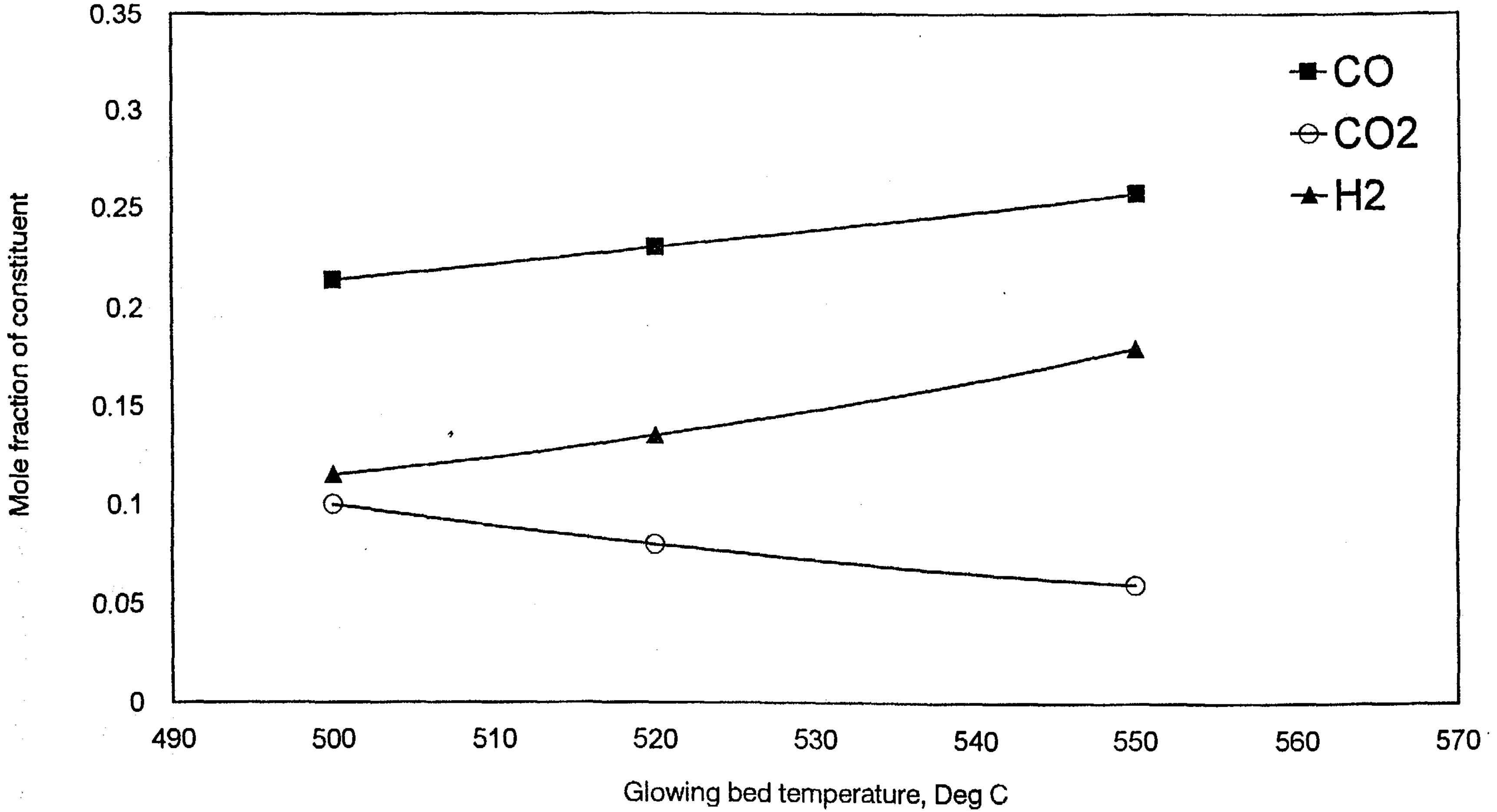


Fig. 5 Influence of glowing bed temp. on CO, H2 and CO2 ingas reactor effluent

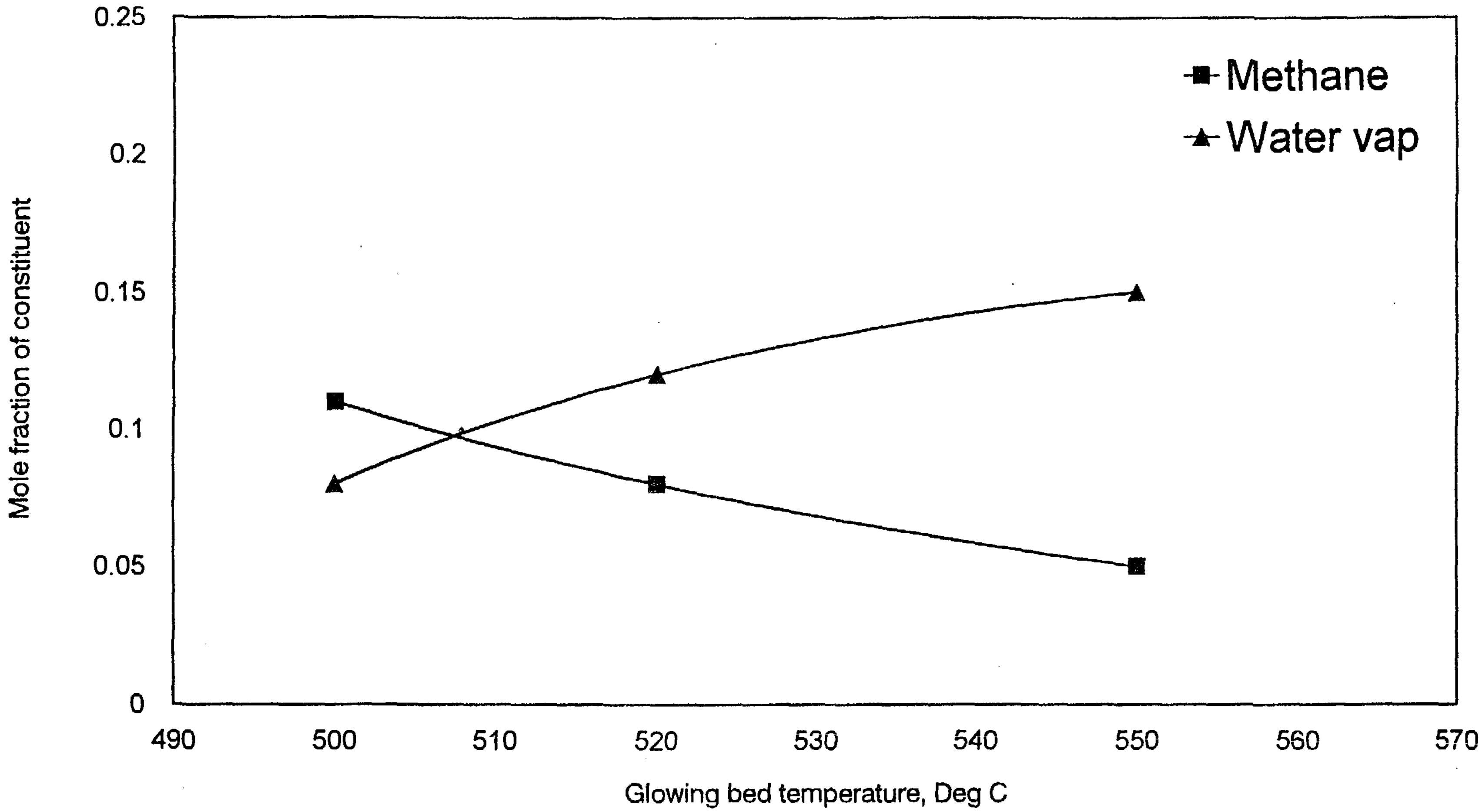


Fig. 6 Influence of glowing bed temp. on methane and water vap. and methane in gas reactor effluent .

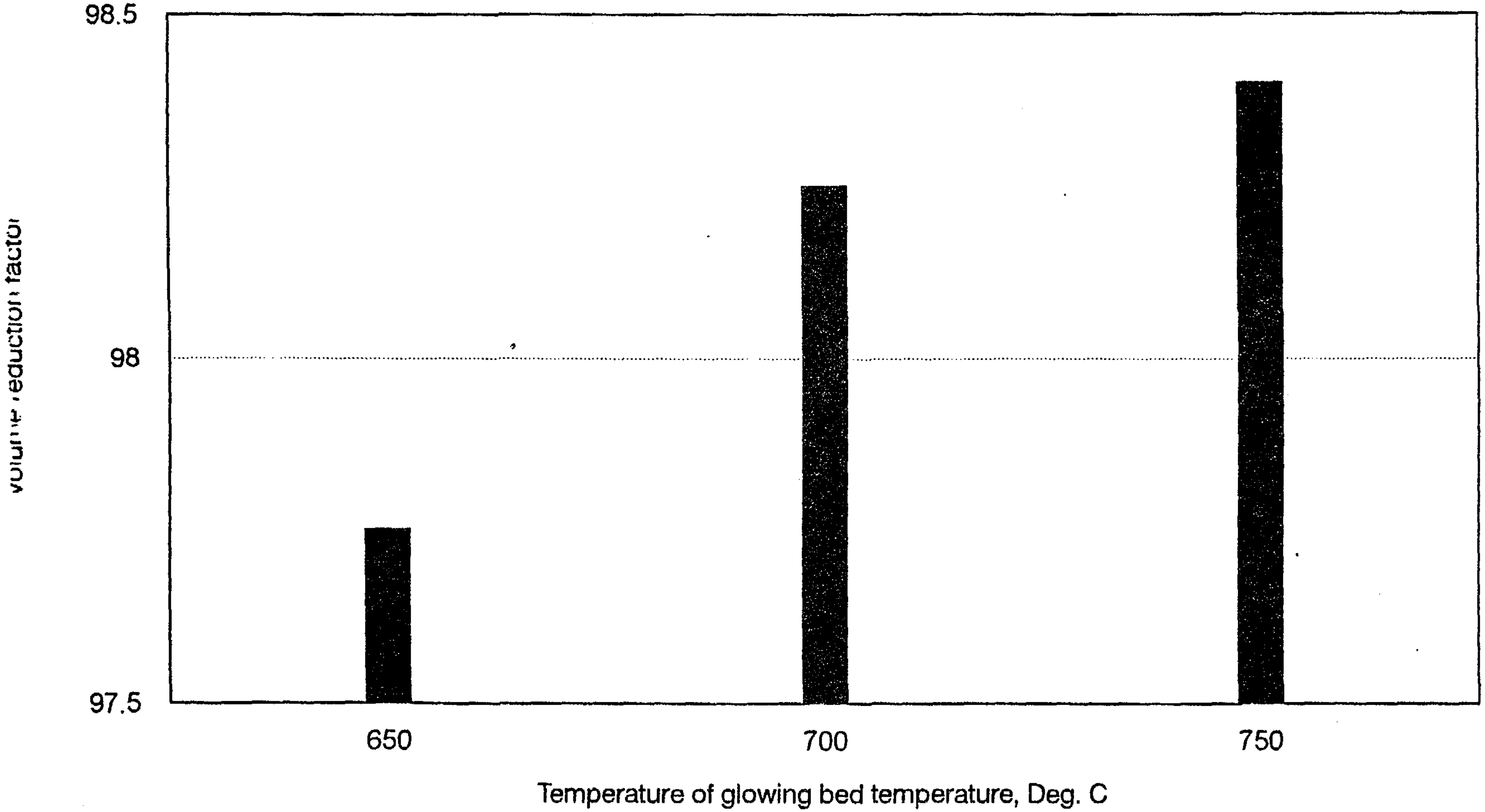


Fig. 7 Volume reduction by incineration