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CHIMISTRY AND INDUSTRY, vol. 13, 6th July 1974, Letchworth, Herts., GB, E. C. POTTER et al.: "Improvement of electrostatic precipitator performance by carrier-gas additives and its graphical assessment using an extended Deutsch equation", pages 532—533

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Method for removing particles from particle-laden gas stream

The use of an electrostatic precipitator for removing particles from gas is indeed well known. Typically, this type of device utilizes the corona discharge effect, *i.e.*, the charging of the particles by passing them through an ionization field established by a plurality of discharge electrodes. The charged particles are then attracted to a grounded collecting electrode plate from which they are removed by vibration or rapping.

This type of precipitator is exemplified in U.S. 3,109,720 to Cummings and 3,030,753 to Pennington.

A common problem associated with electrostatic precipitators is maximizing the efficiency of particle removal. For example, in the utility industry, failure to meet particle emission standards may necessitate reduction in power output (derating). Gas conditioning is an important method for accomplishing this goal as described in a book entitled "Industrial Electrostatic Precipitation" by Harry J. White, Addison-Wesley Publishing Company, Inc. (Reading, Massachusetts, 1963), p. 309. This book is incorporated herein by reference to the extent necessary to complete this disclosure.

An early patent disclosing a gas conditioning method for improving electrostatic precipitator performance is U.S. 2,381,879 to Chittum according to which the efficiency of removal of "acidic" particulates is increased by adding organic amine to the gas, specifically, primary amines such as methylamine, ethylamine, *n*-propylamine and sec-butylamine; secondary amines such as dimethylamine, diethylamine, dipropylamine and diisobutylamine; tertiary amines such as trimethylamine, triethylamine, tripropylamine and triisobutylamine; polyamines such as ethylenediamine and cyclic amines such as piperidine.

Chittum does not disclose the use of alkanolamines as gas conditioners for electrostatic precipitators. However U.S. 4,123,234 to Vossos does disclose the use of what he alleges to be alkanolamine phosphate esters for that purpose and has been patented over Chittum.

The Vossos patent allegedly demonstrates the operability of the alkanolamine phosphate esters as electrostatic precipitator efficiency enhancers through a fly ash bulk electrical resistivity test according to which resistivity of a treated sample in a conductivity cell was determined by applying an electrode to the sample, applying voltages to the cell and measuring voltages across and current through the fly ash. The patent fails to disclose that the additives were ever tested in an electrostatic precipitator. It is doubted by the present inventors that aqueous solution chemistry as utilized in Vossos can be used to predict behaviour of chemicals in the gas system found in electrostatic precipitators. In fact, when tested for efficiency enhancement in an electrostatic precipitator system, it was discovered that these compounds demonstrated little, if any, efficacy. In the tests conducted, the alkanolamine phosphate ester actually decreased efficiency.

Upon further investigation it was unexpectedly discovered that, as compared to the alkanolamine phosphate esters touted by Vossos, tested free base unneutralized amino alcohols were far superior as electrostatic precipitation efficiency enhancers. These compounds will hereinafter be referred to as free base amino alcohols, and any such reference is intended to include mixtures of such compounds.

According to the present invention therefore there is provided a method for removing particles from a particle-laden gas stream using an electrostatic precipitator, characterised by adding to said gas stream from 1 to 200 parts of effective free base amino alcohol additive, per million parts of gas.

Free base amino alcohols consist of molecules containing primary, secondary, or tertiary amines which are unneutralized, that is, they are in the basic form with an unbonded pair of electrons available for reaction. These compounds also have free hydroxyl functionalities and could, accordingly, be subjected to those reactions involving hydroxyl groups.

Quite distinctively from the above-described free base amino alcohols, the alkanolamine phosphate esters of Vossos are prepared by the reaction of alkanolamine with phosphoric acid. As a result, the amine functionality is neutralized making it no longer available to react as an amine. Also, the reaction of alkanolamine with phosphoric acid causes reaction of the alcohol functionality to form the phosphate esters, thus, reducing or eliminating the alcohol functionality present in the molecules.

Amino alcohols can be categorized as aliphatic, aromatic and cycloaliphatic. Illustrative examples of aliphatic amino alcohols are as follows:

ethanolamine
diethanolamine
triethanolamine
propanolamine
dipropanolamine
tripropanolamine
isopropanolamine
diisopropanolamine
triisopropanolamine
diethylaminoethanol

2-amino-2-methylpropanol-1
1-dimethylaminopropanol-2
2-aminopropanol-1
N-methylethanolamine
dimethylethanolamine
N,*N*-diisopropylethanolamine
N-aminoethylethanolamine
N-methyldiethanolamine
N-ethyldiethanolamine
N-2-hydroxypropylethylenediamine
N-2-hydroxypropyldiethylenetriamine
aminoethoxyethanol
N-methylaminoethoxyethanol
N-ethylaminoethoxyethanol
1-amino-2-butanol
di-*sec*-butanolamine
tri-*sec*-butanolamine
2-butylaminoethanol
dibutylethanolamine
1-amino-2-hydroxypropane
2-amino-1,3-propanediol
aminoethylene glycol
dimethylaminoethylene glycol
methylaminoethylene glycol
aminopropylene glycol
3-aminopropylene glycol
3-methylaminopropylene glycol
3-dimethylaminopropylene glycol
3-amino-2-butanol

Illustrative examples of aromatic amino alcohols are as follows:

p-aminophenylethanol
o-aminophenylethanol
phenylethanolamine
phenylethylethanolamine
p-aminophenol
p-methylaminophenol
p-dimethylaminophenol
o-aminophenol
p-aminobenzyl alcohol
p-dimethylaminobenzyl alcohol
p-aminoethylphenol
p-dimethylaminoethylphenol
p-dimethylaminoethylbenzyl alcohol
1-phenyl-1,3-dihydroxy-2-aminopropane
1-phenyl-1-hydroxy-2-aminopropane
1-phenyl-1-hydroxy-2-methylaminopropane

Illustrative examples of cycloaliphatic amino alcohols are as follows:

cyclohexylaminoethanol
dicyclohexylaminoethanol
4,4'-di(2-hydroxyethylamino)-di-cyclohexylmethane
2-aminocyclohexanol
3-aminocyclohexanol
4-aminocyclohexanol
2-methylaminocyclohexanol
2-ethylaminocyclohexanol
dimethylaminocyclohexanol
diethylaminocyclohexanol
aminocyclopentanol
aminomethylcyclohexanol

Of course, the aliphatic and cycloaliphatic amino alcohols can be grouped together under the category alkanolamines.

The amount of free base amino alcohol required for effectiveness as an electrostatic precipitator efficiency enhancer (EPEE) may vary between the limits of 1 and 200 parts of active amino alcohol per million parts of gas being treated (ppm). The optimum amount will, of course, depend on known factors such as the nature of the problem being treated, however, 5 ppm is a preferred lower limit and 100 ppm represents a preferred upper limit. Since the systems tested required at least about 20 ppm active amino alcohol, that dosage rate represents the most preferred lower limit. Furthermore, since it is believed that about 75 ppm active amino alcohol will be the highest dosage most commonly experienced in actual precipitator systems, that represents the most preferred upper limit.

While the treatment could be fed neat, it is preferably fed as an aqueous solution. Any well known feeding system could be used, provided good distribution across the gas stream duct is ensured. For example, a bank of air-atomized spray nozzles upstream of the precipitator proper has proven to be quite effective.

If the gas temperature in the electrostatic precipitator exceeds the decomposition point of a particular amino alcohol being considered, a higher homolog with a higher decomposition point should be used. For example, in certain tests conducted, diethanolamine was not effective as an EPEE at about 620°F (327°C), but a higher homolog, such as triethanolamine, should be suitable at such temperature.

Examples

A series of tests were conducted to determine the efficacy of various amino alcohols using a pilot electrostatic precipitator system comprised of four sections: (1) a heater section, (2) a particulate feeding section, (3) a precipitator proper and (4) an exhaust section.

The heater section consists of an electric heater in series with an air-aspirated oil burner. It is fitted with several injection ports permitting the addition of a chemical and/or the formulation of synthetic flue gas. Contained within the heater section is a damper used to control the amount of air flow into the system.

Following the heater section is the particulate feeding section which consists of a 10 foot (304.8 cm) length of insulated duct work leading into the precipitator proper. Fly ash is added to the air stream and enters the flue gas stream after passing through a venturi throat. The fly ash used was obtained from industrial sources.

The precipitator proper consists of two duct-type precipitators, referred to as inlet and outlet fields, placed in series. Particulate collected by the unit is deposited in hoppers located directly below the precipitator fields and is protected from reentrainment by suitably located baffles.

The exhaust section contains a variable speed, induced-draft fan which provides the air flow through the precipitator. Sampling ports are located in the duct-work to allow efficiency determinations to be made by standard stack sampling methods.

Optical density, O.D., is a measure of the amount of light absorbed over a specific distance. Optical density is proportional to particulate concentration, C, and optical path length, L, according to:

$$O.D.=KLC,$$

where K is a constant and is a function of the particle size distribution and other physical properties of the particle.

Since optical density is directly proportional to particulate concentration it may be used to monitor emissions. Accordingly, an optical density monitor located in an exit duct of an electrostatic precipitator would monitor particulate emissions with and without the addition of chemical treatments to the gases. Treatments which increase the efficiency of a unit would result in decreased dust loadings in the exit gas. This would be reflected by a decrease in O.D. To ensure reproducibility of results, particulate size distribution and other particulate properties, such as density and refractive index, should not change significantly with time.

Accordingly, in the tests conducted, a Lear Siegler RM-41 optical density monitor located in the exit duct-work was used to evaluate precipitator collection performance.

The use of the pilot electrostatic precipitator and optical density monitor for evaluating the efficacy of a chemical treatment as an EPEE is illustrated below in Example 1.

Example 1

Fly ash produced as the combustion by-product of an approximately 1% sulfur coal was found to have a resistivity of 10^{11} ohm-cm at 300°F(149°C). Utilizing this ash type and a flue gas similar to that of an industrial utility plant, pilot electrostatic precipitator studies were performed to determine whether or not a gas conditioning agent could enhance the collection efficiency. The results of the trial are presented in Table 1.

TABLE 1
Results of flue gas conditioning study performed in low sulfur simulation

Parameter	Test #1	Test #2
Chemical feed rate, ppm	0	66
Inlets mass loading, (gr/scf)*	4.1605	4.1605
" " " (gr/scm)**	146.91	146.91
Outlet mass loading, (gr/scf)*	.2314	.0212
" " " (gr/scm)**	8.17	0.75
% Efficiency	94.44	99.49
Optical density baseline	.175	.166
Optical density after treatment	—	.026
% Reduction in optical density	—	84.34

*gr/scf=grains per standard cubic foot
**gr/scm=grains per standard cubic metre. (1 grain is equivalent to 0.0648 g)

As seen in Table 1, the chemical additive at 66 ppm effected an increase in precipitator efficiency of from 94.44% to 99.49%. The significantly enhanced efficiency is also reflected by the 84.3% reduction in optical density.

Example 2

The amino alcohols were tested for EPEE activity using several different industrial fly ashes. The various fly ashes were characterized by known standard slurry analysis, and x-ray fluorescence and optical emission spectra with the following results as reported in Table 2.

TABLE 2
Characterization of fly ash samples

Fly ash designation	I	II	III	IV
% Sulfur in coal	1—4	1—1.2	1.0—1.5	0.5
Resistivity (ohm-cm)	10^{10}	$\leq 10^7$	5×10^{11}	7.6×10^{10}
Slurry analysis:				
Calcium as Ca, ppm	27	14	13	97
Magnesium as Mg, ppm	1.2	11	7	
Sulfate as SO_4, ppm	92	67	44	56
Chloride as Cl, ppm		.6		.6
Total iron as Fe, ppm		.05	.05	.10
Soluble zinc as Zn, ppm			.10	
Sodium as Na, ppm	1.6	3.5	5.9	3.6
Lithium as Li, ppm	<.1	<.1	.2	.6
Inorganic analysis: (weight %)				
Loss on ignition	3	21	4	3
Phosphorous, P_2O_5	1	<1	—	1
Sulfur as S, SO_2, SO_3	—	1	—	1
Magnesium as MgO	—	—	1	1
Aluminum as Al_2O_3	18	17	19	16
Silicon as SiO_2	57	48	66	63
Calcium as CaO	3	<1	1	6
Iron as Fe_2O_3, Fe_3O_4	16	10	6	8
K_2O	2	1	2	1
TiO_2		2	1	
Equilibrium pH slurry	6.9	6.6	8.4	11.7

The results of the tests evaluating the efficacy of various amino alcohols are reported below in Table 3 in terms of % decrease in optical density (% d.O.D.). The column headed "Fly Ash Content" is the amount of fly ash in the gas in grains per actual cubic foot (gr/ACF) and grains per actual cubic metre (gr/ACM). Gas flow rates in the pilot precipitator are reported as actual cubic feet per minute (ACFM) and actual cubic metre per minute (ACMM) at 310°F (154°C) and the SO_2 and SO_3 reported are the respective amounts contained in the gas in terms of parts per million parts of gas. The H_2O is approximate volume % in the gas. The chemical feed rates are parts of active treatment per million parts of gas.

TABLE 3
Evaluation of amino alcohols as electrostatic precipitator efficiency enhancers

Treatment	Dosage (ppm)	Fly ash	Fly ash content (gr/ACF)	Fly ash content (gr/ACM)	Gas flow rate (ACFM)	Gas flow rate (ACMM)	SO_2 (ppm)	SO_3 (ppm)	H_2O (%)	% d.O.D.
N,N diethylethanolamine	61	II	3.40	120.1	152	4.3	726	—	2	42
	94	II	3.40	120.1	152	4.3	726	—	2	65
	47	III	8.87	313.2	154	4.36	451	—	2	93
methylenthanolamine	50	II	3.40	120.1	151	4.28	590	—	2	85
	100	II	3.40	120.1	151	4.28	0	—	2	64
N,aminoethylethanolamine	55	II	3.40	120.1	151	4.28	726	—	2	72
	41	III	8.87	313.2	154	4.36	451	10	2	64
diethanolamine	116	II	3.40	120.1	151	4.28	726	—	2	85
	55	III	4.84	170.9	152	4.3	750	—	2	99
	43	III	4.84	170.9	152	4.3	750	—	3.4	93
	96	III	4.84	170.9	152	4.3	313	—	1.5	86
	43	III	4.84	170.9	154	4.36	726	—	2	90
Triethanolamine	63	I	8.58	303	145	4.11	476	10	1.6	50
	47	I	8.58	303	145	4.11	476	10	1.6	50
monoethanolamine	70	III	4.80	169.5	154	4.36	726	—	—	80
	40	III	9.64	340.4	142	4.02	489	11	2	93

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As can be seen from Table 3, the amino alcohols were effective as electrostatic precipitator efficiency enhancers. While the compounds tested were alkanolamines, it is believed that amino alcohols as a class would be effective for the purpose. Also, while the test gas contained fly ash and SO_2, which are conditions typically found in coal-fired boilers, it is believed that the EPEE's according to the present invention would be effective in other gas systems where particulate matter is to be removed by an electrostatic precipitator.

As a result of these tests, diethanolamine, being the most active compound, is considered to be the most preferred additive.

Example 3

To provide a comparison with a phosphate ester according to the above-noted Vossos Patent, diethanolamine was tested for EPEE efficacy as was diethanolamine phosphate ester made according to the patent.

In preparing the alleged ester, 0.435 mole of phosphoric acid was reacted with 0.435 mole of diethanolamine to yield an equimolar mixture. After allowing approximately 1.35 hours of reaction time, the material was tested.

The results of these tests are reported below in Table 4 in terms of reduction in O.D. (% d.O.D.). The fly ash used was fly ash IV from Table 2.

TABLE 4
Evaluation of amino alcohols as electrostatic precipitator efficiency enhancers

Treatment	Dosage (ppm)	Fly ash content (gr/ACF)	(gr/ACM)	Gas flow rate* (ACFM)	(ACMM)	SO_2 (ppm)	SO_3 (ppm)	H_2O (%)	O.D.	% d.O.D.
None	—	2.90	102.4	152	4.3	400	2	2	0.80	—
diethanolamine phosphate ester	64.9	2.90	102.4	152	4.3	400	2	2	0.94	17
diethanolamine	56	2.90	102.4	152	4.3	400	2	2	0.06	94

*at 310°F (154°C)

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As can be seen from Table 4, the diethanolamine was far superior to the diethanolamine phosphate ester as an EPEE. The negative % d.O.D. value for the phosphate ester run meant that the particle collection efficiency of the pilot precipitator was actually decreased by this compound.

Preliminary results of field trials presently being conducted at a utility plant confirm the above-reported EPEE efficacy studies.

Industrial boiler systems commonly include the boiler proper and heat exchanger means to receive hot combustion gas from the boiler. The heat exchanger can be either an economizer, which uses the combustion gas to heat boiler feedwater, or an air preheater, used to heat air fed to the boiler. In either case, the heat exchanger acts to cool the combustion gas.

The most widely used boiler fuels are oil or coal, both of which contain sulfur. Accordingly, the combustion gas can contain sulfur trioxide which reacts with moisture in the combustion gas to produce the very corrosive sulfuric acid. Since the corrosive effects are, indeed, quite evident on metal surfaces in the heat exchanger equipment, cold-end additive treatments are injected into the combustion gas upstream of the economizer or air preheater to reduce corrosion.

If a boiler is coal-fired, electrostatic precipitator equipment is sometimes provided downstream of the heat exchanger to remove fly ash and other particles from the combustion gas. To improve the efficiency of particle collection, electrostatic precipitation efficiency enhancers are typically added to the combustion gas at a location between the heat exchanger means and the precipitator, that is, downstream of the heat exchanger means.

Based on economic and/or efficacy considerations, it may be desirable to blend various amino alcohols for optimization purposes.

It is understood that the amino alcohol can be fed directly or formed in the gas stream, *e.g.,* a decomposition product.

Claims

1. A method for removing particles from a particle-laden gas stream using an electrostatic precipitator, characterised by adding to said gas stream from 1 to 200 parts of effective free base amino alcohol additive, per million parts of gas.

2. A method as claimed in claim 1, characterised in that said additive is added as an aqueous solution.

3. A method as claimed in claim 1 or 2, characterised in that said additive is free base alkanolamine.

4. A method as claimed in claim 3, characterised in that said additive is water-soluble, aliphatic alkanolamine.

5. A method as claimed in any one of the preceding claims, characterised in that said additive is at least one member selected from the group consisting of monoethanolamine, diethanolamine, triethanolamine, methylethanolamine, *N*-aminoethylethanolamine, and *N,N* diethylethanolamine.

6. A method as claimed in claim 5, characterised in that said additive is diethanolamine.

7. A method as claimed in any one of the preceding claims, characterised in that said additive is added in an amount of from 5 to 100 parts of active additive per million parts of gas.

8. A method as claimed in claim 7, characterised in that said additive is added in an amount of from 20 to 75 parts of active additive per million parts of gas.

9. A method as claimed in any one of the preceding claims, characterised in that said additive is sprayed into said gas stream.

10. A method as claimed in any one of the preceding claims, characterised in that said gas stream is the combustion gas of a boiler system fired by sulfur-containing coal.

11. A method as claimed in any one of the preceding claims, characterised in that said gas stream contains fly ash.

12. A method as claimed in any one of the preceding claims, characterised in that said gas stream contains sulfur dioxide.

13. A method as claimed in any one of the preceding claims, characterised by use of a precipitator system comprising heat exchanger means for cooling said gas stream and electrostatic precipitator means connected to said heat exchanger means for receiving said cooled gas stream, and characterised in that said amino alcohol is added to said gas stream at a location between said heat exchanger means and said electrostatic precipitator.

Revendications

1. Procédé pour éliminer des particules d'un courant de gaz au moyen d'un dispositif de précipitation électrostatique, procédé caractérisé en ce que l'on ajoute au courant gazeux 1 à 200 parties d'un amino-alcool, à l'état de base libre efficace, par million de parties du gaz.

2. Procédé selon la revendication 1 caractérisé en ce que l'additif est ajouté en solution aqueuse.

3. Procédé selon la revendication 1 ou 2 caractérisé en ce que l'additif est une alcanolamine à l'état de base libre.

4. Procédé selon la revendication 3 caractérisé en ce que l'additif est une alcanolamine aliphatique soluble dans l'eau.

5. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que l'additif est constitué par une ou plusieurs substances choisies parmi la monoéthanolamine, la diéthanolamine, la triéthanolamine, la méthyléthanolamine, la N-aminoéthyléthanolamine, et la N,N-diéthyléthanolamine.

6. Procédé selon la revendication 5 caractérisé en ce que l'additif est la diéthanolamine.

7. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que l'additif est ajouté dans une proportion de 5 à 100 parties d'additif actif par million de parties du gaz.

8. Procédé selon la revendication 7 caractérisé en ce que l'additif est ajouté dans une proportion de 20 à 75 parties d'additif actif par million de parties du gaz.

9. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que l'additif est pulvérisé dans le courant gazeux.

10. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que le courant gazeux est le gaz de combustion d'un système de chaudière chauffé par un charbon contenant du soufre.

11. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que le courant de gaz contient des cendres volantes.

12. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que le courant de gaz contient du dioxyde de soufre.

13. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que l'on opère avec un dispositif de précipitation comprenant un échangeur de chaleur pour refroidir le courant gazeux et un système de précipitation électrostatique relié à l'échangeur de chaleur et qui reçoit le courant gazeux refroidi, et en ce que l'amino-alcool est ajouté au courant de gas en un point situé entre l'échangeur de chaleur et le système de précipitation électrostatique.

Patentansprüche

1. Verfahren zur elektrostatischen Abscheidung von Schwebstoffen aus einem Gasstrom, dadurch gekennzeichnet, daß man dem Gasstrom 1 bis 20 ppm Aminoalkohol als freie Base zusetzt.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß man den Aminoalkohol als wässrige Lösung zusetzt.

3. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß man als Aminoalkohol ein Alkanolamin zusetzt.

4. Verfahren nach Anspruch 3, dadurch gekennzeichnet, daß man ein wasserlösliches aliphatisches Alkanolamin zusetzt.

5. Verfahren nach Anspruch 1 bis 4, dadurch gekennzeichnet, daß man als Aminoalkohol Monoethanolamin, Diethanolamin, Triethanolamin, Methylethanolamin, N-Aminoethylethanolamin und/oder N,N-Diethylethanolamin zusetzt.

6. Verfahren nach Anspruch 5, dadurch gekennzeichnet, daß man Diethanolamin verwendet.

7. Verfahren nach Anspruch 1 bis 6, dadurch gekennzeichnet, daß man 5 bis 100 ppm Aminoalkohol dem Gas zusetzt.

8. Verfahren nach Anspruch 7, dadurch gekennzeichnet, daß man 20 bis 75 ppm Aminoalkohol dem Gas zusetzt.

9. Verfahren nach Anspruch 1 bis 8, dadurch gekennzeichnet, daß man den Aminoalkohol in den Gasstrom einspritzt.

10. Verfahren nach Anspruch 1 bis 9, dadurch gekennzeichnet, daß der Gasstrom ein Abgas aus einer Kesselanlage ist, in der schwefelhaltige Kohle verfeuert wird.

11. Verfahren nach Anspruch 1 bis 10, dadurch gekennzeichnet, daß der Gasstrom Flugasche enthält.

12. Verfahren nach Anspruch 1 bis 11, dadurch gekennzeichnet, daß der Gasstrom Schwefeldioxid enthält.

13. Verfahren nach Anspruch 1 bis 12, dadurch gekennzeichnet, daß man in einem Wärmeaustauscher den Gasstrom abkühlt, den abgekühlten Gasstrom in einen elektrostatischen Abscheider leitet und den Aminoalkohol in den Gasstrom zwischen Wärmeaustauscher und elektrostatischem Abscheider einbringt.