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THE PRACTICAL AND SCIENTIFIC SOLUTION OF THE SMOKE NUISANCE.

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A T H E S I S.

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by

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With a degree of accuracy heretofore unknown, in the latter part of the eighteenth century, the great French Chemist Lavoisier was the first to clearly conceive and explain the phenomenon attending combustion, and the various incomplete applications of same throughout the world results in the "smoke nuisance".

Possibly the first record we have of the time at which the said nuisance was publicly taken notice of, occurred in London, England, during the thirteenth century, when, for the cause of public health in the year 1273, the burning of coal was prohibited by law. In various parts of the world, principally in large cities, numerous societies for the abatement of the smoke nuisance have been formed and some little success has been achieved. However, each particular place has its own special cause and smoke doctors must be graduated, who knowing the fundamental principle underlying the smoke trouble, are, after a careful diagnosis, able to prescribe the scientific remedy consistent with the possible financial conditions for each class of offenders. A notable example of the lack of knowledge of the laws of combustion was displayed when the American designed water tube boilers were sent over to England to burn bituminous coal. This boiler burning Pennsylvania anthracite, which is practically smokeless, could not smoke even though it wanted to, so its sponsors disarmed by its performance and ignorant of the underlying principle of combustion, hailed it as the acme of perfection in the consumption of smoke producing fuel. The result was all kinds of trouble from too much smoke, resulting in the imposition of fines, the use of higher price smokeless fuel and finally the direct attribution of "skies plastered with soot" resulting from the use of the said steam boiler, together with the further imputation of alienship of its sponsors to the knowledge governing the necessary fundamental laws in the case.

Again the evolution of cross water tube boilers was a glaring example of the lack of knowledge of these same laws.

Essential Requirements for the Successful Combating of the Smoke Nuisance.

I. As aforesaid, the smoke doctors must possess a thorough knowledge of the fundamental laws, both direct and indirect, of combustion.

II. A careful study must be made of the smoke nuisance in the locality where it is proposed to eliminate same. This would include an examination of the quantity and quality of the various fuels used.

III. A classification must be made of the smoke produced, together with an estimate of the proportion of smoke produced and damage inflicted by each class.

IV. The classification having been arrived at with the respective damage inflicted by each, means scientifically correct and financially applicable are to be adopted or recommended, as the case may be, governing the respective classes.

V. The passage of laws or ordinances in accordance with the findings along the above indicated lines.

VI. The appointment of competent inspectors, who will carefully inspect with all means at their disposal, and report all offenders of the laws or ordinances that may have been passed for the purpose of governing the various classes of smoke producers.

VII. A rigid enforcement of the laws and ordinances against all smoke offenders, whomsoever they may be.

VIII. Education of the people at large, as to the best methods of economical fuel consumption, whereby much of the domestic and other smoke can be eliminated.

Though the smoke nuisance is an old one, it is a well settled fact among scientific men that same can be satisfactorily eliminated,and is really an absolute waste of fuel, together with the annoyance and injury to the people at large. Much blame can be laid at the door of the "financial boards" that govern large smoke-producing institutions, as cheap first cost of installation is generally the rule that is followed, and the same will apply in quite a few cases to other smoke producers.

Evidence of the truth of this assertion can be stated in the success attained by the various smoke abatement societies abroad, notably in London and Hamburg. Also in Germany better results have been accomplished, due to the fact that men with scientific training are to be found at the head of the various enterprises, together with expensive fuel and rigid laws, whereby cheap first cost of installation is regarded as a fallacious policy.

It might be also said that in many places the idea has gained a footing that soft or bituminous coal cannot be burned without smoke, hence it is useless to attempt to prevent same. This is an incorrect impression and will require a great deal of work to overcome.

Numerous plants burning bituminous coal are doing so practically without the emission of any undue amount of smoke, so that the problem seems to resolve itself into the "representatives" of the people determining the practical solution of the problem, then rigidly enforcing its observance.

Combustion

Combustion of the ordinary fuels may be defined as the highest possible state of oxidization of the free or combined carbon with oxygen, as imperfect combustion is generally the result of the phenomenon, it may possibly be well defined as "A chemical union of carbon and oxygen whereby some heat is evolved."

The final reaction will be carbon dioxide and water.

$C + o = Co =$ carbon monoxide

$Co + o = Co_2 =$ carbon dioxide

$2\ H + o = H_2o =$ water.

These reactions appear simple enough and the combustion of fuel was for a long time thought to be a somewhat simple affair. Today, scientists are aware that it is a series of complicated chemical reactions.

Complete combustion requires:

1 - Air
2 - Space
3 - Time
4 - Proper Mixture
5 - Temperature.

In considering the prevention of smoke and in view of the above definition of combustion, the fulfilling of same leads us directly to obtaining the greatest amount of heat possible from the fuel in question by supplying the necessary amount of air, which has been found to vary from 5% to 100%.

1. The theoretical amount of air necessary being approached only in certain special cases of installations,

With gas at 600° and air at 50° - 20% to 100% air needed.
With gas and air at 1000° - 10% " "

In a gas producer - 5% air needed.

In dust fuel consumption small excess of air needed, 19# of air to the pound of combustible has been found to give the best results.

2. SPACE sufficient for the complete reactions of combustion to take place must be allowed, otherwise imperfect consumption of fuel will result with the evils attending it.

3. TIME - Bad effects will be noticed if the velocity, either by natural or artificial draft, is such that the travel of the gas through the installation is too rapid, as the heat from the gases will not be extracted from them and will consequently be lost up the chimney, and together with the breaking of the continuity of the flame, a velocity of at least thirty feet per second is necessary to supply sufficient atmospheric oxygen for good combustion.

4. PROPER MIXTURE - Explosions occur when combustible gases or vapors become uniformly mixed and the reaction extends throughout the mass, all at the same time.

Improper mixture may also result in part of the gases being burned while others are not.

5. TEMPERATURE - of combustion must be carefully regulated with due regard to the fuel. Too high a temperature will cause smoke and fuel loss, and too low a temperature is also a fruitful source of smoke, as in this case the process becomes one of distillation, and as ordinary fuel does not contain sufficient oxygen to unite and carry off the total carbon, the hydrogen burns off and carbon is evolved as smoke. This, along with lack of air, is the chief reason for the evolution of volumes of smoke when green fuel is first put on the fire.

In the combustion of fuel, very little smoke is evolved due to the free carbon contained therein. The real cause is due to the unconsumed carbon deposited by the cooling of hot dessociated hydrocarbon gases. As an example, the heaviest gas product of fuel decomposition will be taken, namely, ethyl gas, which on heating at a certain temperature will yield free carbon and ethylene according to the reaction as expressed below:

$$C_4H_4 + heat = 2\ C + C_2H_4$$

so that if the proper conditions for complete combustion are lacking the free carbon will be finally deposited as soot. Other hydrocarbons contained in the volatile portion of fuel act the same way, whereas on the other hand, with the necessary requirements, the free carbons separated out will be consumed finally to carbon dioxide gas and the ethylene will finally be voided as carbon dioxide and water which represents complete combustionand no smoke.

Fuels are sources of heat energy that can readily be utilized by combustion in air. They may be stated as

1 - Solid

2 - Liquid

3 - Gaseous

Under Class 1 but two divisions would be made for the purpose of this work, referring strictly to anthracite insofar as under that heading all reference would be made to such fuels as could be burned practically smokelessly, all others being considered as bituminous, that burned with some degree of smoke that had to be abated.

Anthracite produces less smoke than bituminous coal because the oxygen exists in greater proportion, whereby a greater percentage of colorless carbon dioxide and carbon monoxide will be formed, necessarily with a lesser amount of hydrogen combinations, in bituminous coal, the reverse situation exists, hydrogen preponderates with the accompanying combination, which at various temperatures to which they are exposed, break down into carbon and lighter hydrocarbon combinations, and, under the imperfect condition of combustion in which they are consumed, are a prolific source of smoke.

Class 2. Liquid fuels, whenever they admit of being used, are very satisfactory, being easily burned without cinders or ashes, and, most important of all, without smoke. Crude oil at present is being used very successfully in many large establishments. The oil is mechanically divided as finely as possible, either by means of steam or air (preferably hot), under pressure through fine jets, imparting a whirling motion, so that the laws of perfect combustion admit of pretty nearly absolute exemplification. In large operations with bituminous coal at $4 to $4.50 per ton, preference is given in many cases to crude oil at $1 to $1.25 per barrel.

Class 3. Gaseous Fuels. Under this heading is meant the use of all kinds of gaseous fuel, natural or artificial. Artificial gas is to be found only in limited areas so that artificial producer gas is chiefly concerned. All kinds of fuel can be used. Each, however, has its particular advantage. As in Class 2, combustion can be practically thorough so that smoke is avoided and the efficiency will reach as high as 80% or better.

In small installations, it can hardly compete with solid fuel due to higher cost of installation, some little prejudice and possibly some well founded trouble with fuel. However, the fuel question is one that time and experience will entirely overcome and with which gas producer practice will make great strides.

Combustion of Fuels

The combustion of fuel is effected in four different ways:

1 - Direct firing

2 - Gas firing

3 - Partial gas firing

4 - Dust firing

1. Direct firing, as the name implies, means adding the fuel directly to the fireplace, and can be said with authority that in the case of bituminous coal, it is practically impossible to prevent smoke.

By careful regulation of air, it has been found possible to reduce the period of dense smoke making to an average of 89 minutes per day of ten hours. By side firing and front admission of air, the smoke period can be reduced to 40 minutes.

It has been demonstrated that, by extreme care in side firing and careful regulation of the air at the front and bridge together with a good draft, that the smoke period could be reduced to 16 minutes per ten hours.

The competitive tests in Paris, France, have practically demonstrated the fact that hand firing is smoky and to make it non-smoky requires too much expense.

2. Gas firing. Under this head is generally understood the gasification of any suitable fuel, for use as "producer gas" known under various different names as "air gas", "fuel gas", etc. The fuel efficiency is very satisfactory, likewise the smokeless qualities and when the minor objections noted in Class 3 - Gaseous Fuel - will have been overcome, an efficient remedy will be at hand for certain phases of industrial smoke.

3. Partial Gas Firing, in which grates inclined and stepped are the chief factors. With step grates, cheap waste fuels, such as spent tan bark, sawdust and slack can be utilized. In inclined grates, fine fuel, clinker and strong coking coal are to be avoided, otherwise good results can be obtained. It night be noted that in both these subdivisions some little attention is required.

4. Dust Firing. Doubtless this mode of firing will become more generally used, and from the fact that about 97% of the carbon of the fuel can be gasified and that practically the theoretical amount of air is sufficient, the practically perfect combustion of fuel can be nearly realized. Any fuel can be used; provided it is pulverized to 50 mesh or finer, no previous drying is necessary. The simplest explanation for the near perfect factors of ideal combustion in this method of firing is that here are to be found the combined effects of fuel, reduced sufficiently close to its molecular size so that, when by mechanical means it is quickly supplied with its chemical mate, the reaction is likewise near the point of perfection, resulting in the high utilization of the total contained carbon, the space being about one-fifth of that necessary in gas producers for the reaction to take place.

Other advantages are, continuous uniform work after the "feed" has been proportioned, temperature, depth of firebed, clinkers and other difficulties are eliminated. The difficulty with the fine ash in dust firing has been overcome and possibly today it represents the latest and most modern achievement in fuel utilization inasmuch as any fuel can be used even up to a content of 70% ash.

By way of comparison, it might be stated that with fuel efficiency in steam boilers at 60% to 75% and of 80% in gas firing and of 97% in dust firing, the superiority of the latter method will cause it to take the lead in all operations where it can possibly be used.

Briquet Firing.

The briquetting and use of fuels has made very little progress in America as compared to Europe, especially. The tolerance of the smoke nuisance and plenty of good fuel at a relatively low price has encouraged all sorts of negligence toward any extensive attempts at utilizing the low grade fuels that are to be found in various parts of the country. Extensive experiments made with different kinds of fuel, especially those of comparatively low value, have demonstrated the fact that briquetting in the future will play a very important part in the fight being waged against the smoke nuisance, also in the utilization of fuels that have heretofore been regarded as little more than useless, and even in some cases have been burned up as a means of getting rid of same.

The chief thing to be observed in the making of briquets is the choice of a binder and fuel suitable for the purpose for which the briquets are intended. Briquets possess many points of advantage over raw fuel. A few of these that might be mentioned are:

1. The possibility of avoiding smoke by the proper choice of fuel and binder.
2. Less care need be given the fire.
3. A hot fire can be had in a shorter time.

4. No danger of spontaneous combustion.

The cost of making briquets, exclusive of fuel, will range from 85¢ to 95¢ per ton. Inclusive of fuel, the same figure would be $2.50 to $4.50 per ton, the difference in cost being due to the price of the various fuels that might be used. A plant with a capacity of 100 tons of briquets per day will cost from $85,000 to $95,000.

Heat Losses - Causes Smoke.
Possible Sources of Heat Losses from the Zone of Combustion Whereby Smoke Can Be Produced.

I. The passage out of the chimney of gases at a higher temperature than necessary act as a heat robber, and tend to lower the temperature required for good combustion, whereby the formation of smoke is made possible.

II. The presence of moisture which requires heat to be evaporated, also the partial decomposition of said moisture into hydrogen and oxygen without sufficient heat for the combustion of said gases whereby an equivalent of heat is returned, also acts as a heat robber as mentioned in I. When fuel is dried before using this source of heat loss and consequently source of smoke production is avoided.

III. The necessary heat required to cause the chimney draft is by far more important than ordinarily thought to be, whether the installation is hand or mechanically fired or is equipped with natural or artificial draft.

As more oxygen in the form of air is required in practice to maintain combustion than theoretical considerations demand, it is evident that the fire chamber demands its share of careful consideration in its construction, and, that the feeding of fuel in order to obtain combustion practically in accordance with the smoke conditions imposed by law or ordinances passed in the respective localities, requires some little education together with a faithful performance of duty on the part of the person in charge.

Stoking Losses

As the ideal consumption of fuel is never attained and even good practical results approached, possibly only in large installations, where cheap first costs are not considered, the ordinary way of stoking might be regarded as consisting in opening the fuel door wide, thereby giving the combustion chamber a good breath of cold air which is followed by a worthy companion, namely, a thick layer of cold fuel, together with the contained moisture. Now the foundation has been well laid for loss of heat and an abundance of smoke. The fuel door is closed and the fuel box has now been turned into a temporary slow distillery.

The deep fuel bed prevents the incoming of the necessary amount of air and the cooled fire box furnish the required condition for the escape of the combustible hydrocarbon gases up the chimney, in the form of smoke and fuel loss, instead of being consumed for the production of heat.

2. The same gases also carry along with them a considerable amount of heat which is another source of loss.

3. The fire now being in normal condition, the carbon dioxide, which has been formed during the imperfect condition above noted, is deoxidized at the expense of the fuel which has to supply the necessary amount of carbon to unite with the extra atom of oxygen taken on by the carbon monoxide during the slow distillation of the fuel above described.

4. Another source of loss of heat may be stated in connection with the opening of the fuel box door, namely, the accelerated draft increases the velocity of the travel of the gases to such an extent that instead of depositing their heat for the purpose of the installation, they carry away the heat with them. This applies more particularly to draft in general than merely in the opening of the feed box door.

Mechanical stokers of the most approved pattern and skillfully attended, feed the fuel in such a way that the volatile matter is gradually expelled in the presence of a sufficiency of air and proper temperature whereby the ideal conditions of complete combustion are more closely approached, with the accompanying result of less smoke and better recovery of heat values.

In exemplification of this, it may be stated that tests made in France, in competition lasting over several years for prizes, have demonstrated the fact that mechanical stokers could feed fuel so that it could be fumivorously consumed. It should be added that when the apparatus was simple and plain, that there was some expense attached to its installation, and in another case where practical results were deemed to be equally as good, skilled attendance was required. In England, tests have demonstrated the fact that with the proper regulation of stoking, air and temperature, the production of smoke could be avoided and much fuel saved.

The smoke nuisance as described in this thesis will be divided into three parts.

1. That from private dwelling houses strictly.

2. That from all industrial, mercantile and financial enterprises.

3. Noxious fumes resulting from smelting, chemical and all other allied industries.

Part I.

That eminating from private dwelling houses and caused principally from unconsumed carbon, being permitted to escape in the atmosphere in the form of soot, chiefly in the production of heat for all domestic purposes, and very likely representing not over one quarter of the trouble, and possibly, if alone, responsible for the smoke nuisance, would hardly be noticed; as it is produced in comparatively small isolated quantities, which become very much diluted from the surrounding atmosphere, so that the total volume tends to become thinly dissipated and practically harmless and unnoticed. However, in large cities, any small amount of smoke becomes a menace when same is added to the already large amount of smoke evolved from the industrial pursuits under Part II. Hence, methods financially consistent with the means of the people at large must be used, which will minimize such smoke as much as possible.

Means for the Prevention of Domestic Smoke.

1. The use of briquetted form of fuel, known as "eggets", can be made a very satisfactory form of domestic fuel for use in the elimination of smoke.

2. The use of a cheap, non-illuminating gas distributed in a separate system is also very feasible.

3. Such other means as electricity, coke and central power stations can also be utilized with good result when possible.

4. The use in all cook stoves, ranges and heating stoves, of the partial or complete gasification method as practised in the down-draft system of consuming fuel.

COOK STOVES AND RANGES WITH AND WITHOUT BOILER CONNECTIONS FOR HOT WATER

Fig. A. - represents an ordinary cook stove or range which is fitted with two grates, one above the other, at from six to twelve inches apart, depending on the size of the stove. The fuel is placed on the upper grate and when being consumed, the flames and products of combustion are drawn down through the bed of fuel on the upper grate so that the heat is almost entirely generated between the two grates, and is diverted from this point over and around the oven, as in an ordinary cook stove, or range, until it finally goes up and out of the chimney. After the fire has been started some time and there is a bed of glowing coals on the top grate, the addition of fresh fuel on the top grate will produce practically no smoke, for the reason that the top of the fuel on the top grate is not ignited, while the bottom of the fuel on the top grate is a glowing mass of coal. Now, as fresh fuel is added, and in burning it generally settles down on the grate, the combustible gases and volatile hydro-carbons which, in the old system of top draft, are driven off

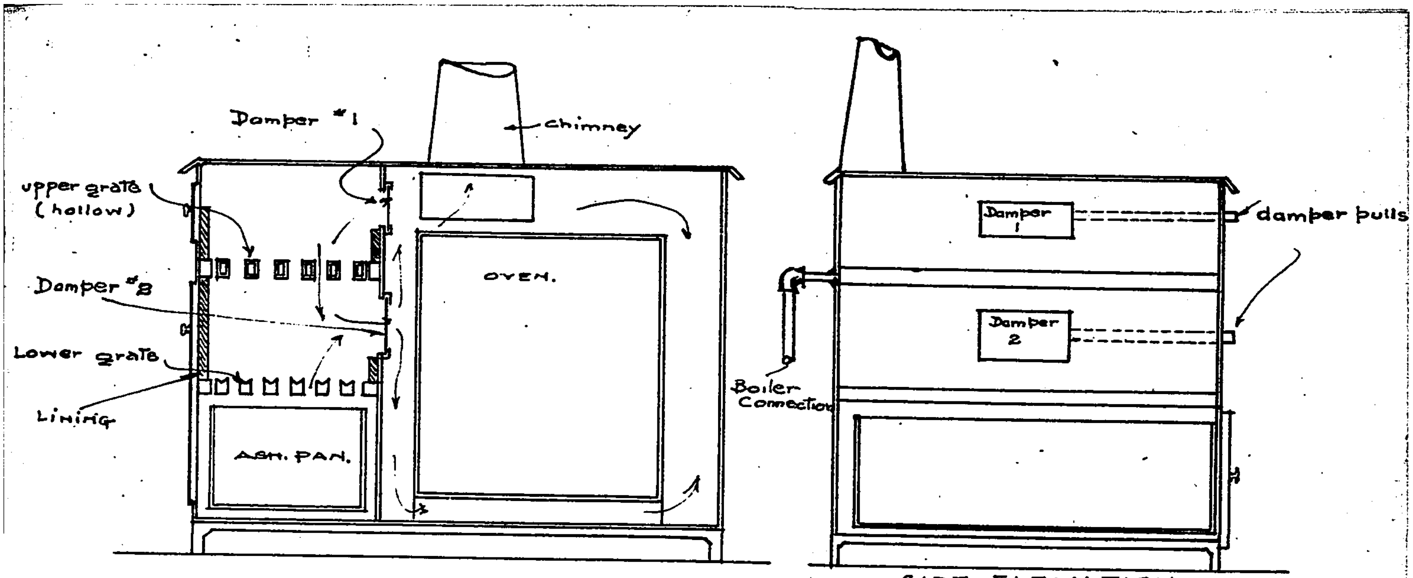


FIG A. - COOK-STOVE

-SIDE-ELEVATION-

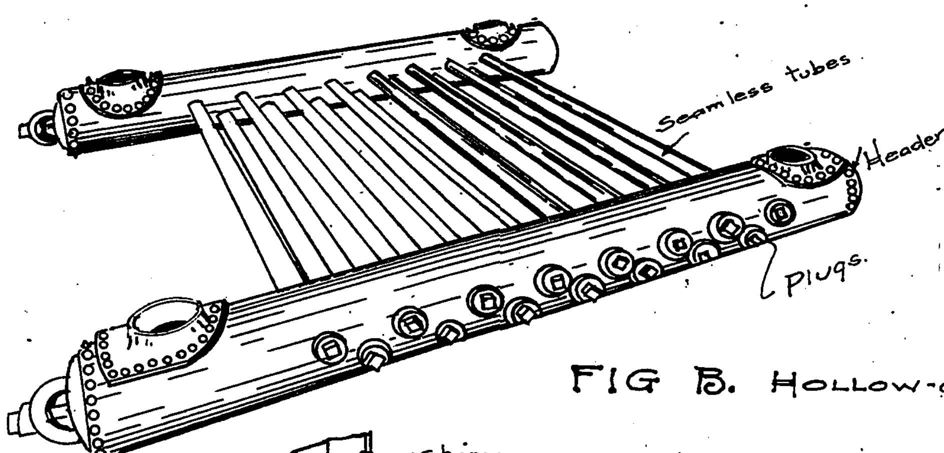
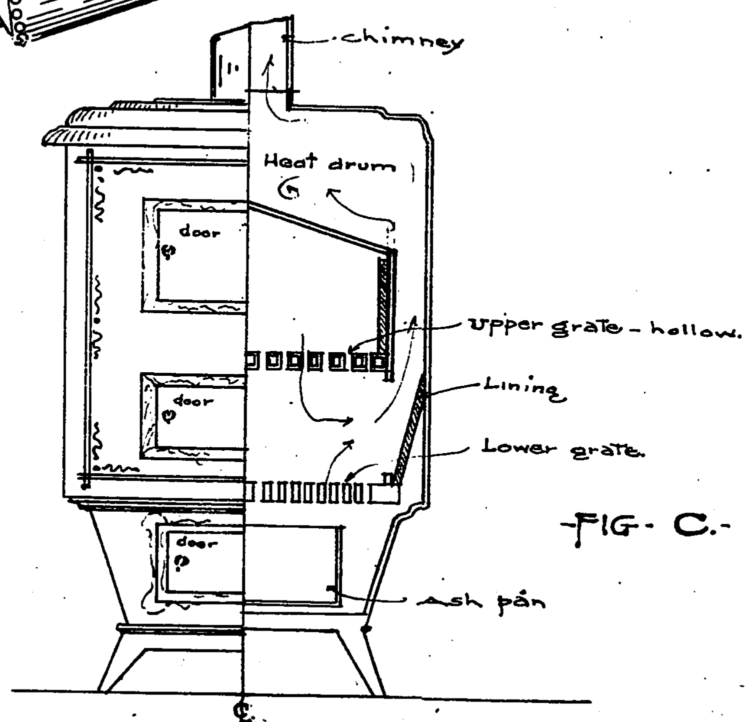


FIG B. HOLLOW-GRATE



-FIG- C.- HEATING-STOVE

-ELEVATION- & SECTIONat a temperature below their ignition point and lost up the chimney, whereas in the gasification method these gases and volatile hydrocarbons pass down through the bed of glowing coals. The volatile hydrocarbons are decomposed, their carbon is deposited on the glowing coals and together with the combustible gases are consumed in producing heat instead of passing up the chimney and becoming a source of loss of fuel and a nuisance in the form of soot. The bed of glowing coals also filters and retains all particles of carbon or other carbonaceous matter that has a tendency to be carried away either by the heat or by the draft of the chimney. The lower grate is made of ordinary cast iron, the bars are set close so that particles of unconsumed fuel that fall through the upper grate are caught and consumed, hence the consumption of fuel is limited to that of solid fuel on the upper grate together with a small amount of fuel free from volatile hydrocarbon that happens to fall on to the lower grate, and in consequence of its freedom from volatile hydrocarbon will burn practically smokeless. A large per cent of the combustible gases which heretofore in the old system has gone up the flue, is, after its carbon has become fixed by its passage through the bed of glowing coal on the upper grate as above described, consumed between the two grates, and its fuel values recovered, which in the case of anthracite coal amounts to 8% to 12% volatile matter with a heat value of 9200 to 9500 British Thermal Units, and with bituminous coal, volatile matter from 32% to 50% and 11,500 to 13,000 British Thermal Units.

When there is no boiler connection for hot water desired, both grates can be made of cast iron. When the boiler connection for hot water is desired, a hollow pipe grate, as per Fig. B, is used, which can be connected up to an ordinary kitchen boiler in the ordinary manner. Said grate is made of steel, the grate bars being made of seamless steel pipes or heavy wrought iron pipe, the ends of which are fitted with plugs permitting of easy cleaning. The grate tube headers also have their ends fitted with plugs. These grates admit of easy repairs and the circulation of water in them is excellent, thereby the formation of scales is almost nil. Hot water at any temperature and in any amount is abundantly supplied for all household purposes.

Damper #1 - is provided so that if a modified top heating of the stove is desired, same can be had by opening said damper.

Damper #2 - is closed in case that absolute top heating is desired. In either case the range or stove can be used under either system without any of the effects of either system being modified. In interchanging to the top draft system, a little time should be given to allow the burning off of smoke producing gases when fresh coal is put on the fire.

HEATING STOVES WITHOUT BOILER CONNECTIONS FOR HOT WATER.

Fig. C. - represents an ordinary heating stove. Solid double grates are used and the hot gases from the fuel, after being burnt between the grates, circulate between the inner and outer shell of the stove, thereby radiates the heat and finally escapes out of the chimney. The stove is constructed like an ordinary heating stove with the exception that the outer shell of the stove is practically a heat drum in which the burned gases are allowed to give off their heat before being permitted to escape up the chimney. Eeither the top of the stove is removable, in which case the stove pipe is placed at the back, or the front of the stove is removable, in which case the stove pipe can be placed on ~~the~~ top of the stove; the purpose of the removable parts of the stove being that the fire box can be placed in same and can be taken out at any time for repairs or alterations by simply removing four thumb screws from either the top or the front of the stove. The fire box is constructed of sheet iron of suitable weight, and that part over the upper grate has a sloping roof which permits of being readily cleaned. The sides of the fire box around the upper grate can be lined either with cast iron staves or fire bricks, depending on the duty to be performed. The side spaces between the upper and lower grates are also lined with cast iron staves or fire brick, suitable openings being left to permit the flame and burning gases to pass into the upper part of the stove or heating drum. Any ash or dirt matter that goes up into the drum falls back down on to the level of the door of the lower grate and can be easily cleaned out through said door. The bottom of the stove comprises the ash pan and box, and can be constructed of one thickness of iron as it is not subject to any high heat. Air in sufficient amounts is admitted through suitable holes in the upper door as in ordinary stoves.

In reality, it is one stove within another. The fire box constitutes the inner stove in which the fuel both fixed and volatile is completely consumed, the outer shell or stove being a radiator of the heat produced by the burning gases. Hence, the total fuel values in the fuel being consumed as thoroughly as possible, 90% to 95% of the smoke evolved in the old method is hereby prevented, and a gain of from

18% to 20% is made in the form of additional heat values recovered from the same coal being burned under the new condition.

Part II.

That eminating from all industrial, mercantile and financial enterprises, including rooming houses, apartments and hotels, where light, heat and power are generated.

Under this part the bulk of the nuisance and damages resulting from smoke is chargeable, and after careful consideration of the various conditions, the following apportionment of actual smoke accumulation and damage is made for Salt Lake City, Utah:

Private houses strictly -	Smoke	produced	25% -	Damage	caused -	15%
Industries and enterprises ~~Smelteries~~ Locomotives, etc. Furnaces, kilns, etc.	" "	" "	43%(12%)	"	"	65%
Hotel, rooming houses and business property -	"	"	20% 100%	"	"	20% 100%

The smoke produced by private houses amounts to more than 25%, but observation tends to show that but 25% of same accumulates and that the damage from it is comparatively small. The proportion of smoke caused by strictly domestic uses is the object of much discussion in England. In certain cities it is placed as high as four-fifths of the total amount. Again, in the City of Leeds, said to be one of the smokiest cities in Scotland, authorities do not agree on this figure, and in ~~one~~ our case the figure is altogether too high. The high percentage of smoke chargeable to domestic production in England is, without doubt, due to the old fashioned English fireplace, wherein fuel recovery and smokelessness are sacrificed to cheerfulness.

Whereas, under Part II, the smoke is emitted in an already impoverished atmosphere laden with dust and other impurities and with a tendency to hang instead of readily dispersing, hence it inflicts the bulk of the damage. The per cent of damage has been arrived at by repairs mecessary to property situated in the immediate business center and that located away from the business center.

In large American cities, as Chicago, the following estimate is made:

Railroads -	43%
Stationary Steam Plants	30%
Industrial furnaces and heating plants	18.5%
River crafts	4%
Domestic heating plants	4.5%
	100.0%

The total damage estimated amounts in the United States to $500,000,000 per annum and is apportioned as follows:

Loss of fuel values -	$90,000,000
Sickness and impairment of health -	270,000,000
Extra cost of living and business expense due to dirt, etc.	140,000,000

In Cleveland, the damage is estimated at $12.00 per capita; in other cities, at four-fifths of the value of the coal consumed. In London, England, the fuel values wasted are estimated at a quarter of the total estimated economic loss.

Most all large cities have passed smoke ordinances allowing smoke to be produced from 5 to 10 minutes each hour with certain exceptions, and have also appointed inspectors who examine and compel all old installations and projected new ones to conform to the ordinances. By the installation of smoke meters wherever it is thought necessary that automatically register the smoke and length of time, the inspectors are able to more easily detect the habitual offenders.

As outlined in Part I, the gasification method of consuming fuel can be advantageously used and with proper city ordinances and installations of smoke meters with the worst offenders, and competent inspectors to enforce the ordinances, the smoke nuisance can be reduced from 90% to 95%, and wherever installed the down-draft system of fuel consumption has effected a saving of from 13% to 26% in fuel values.

Ordinary losses in carbon in the form of soot where the smoke nuisance has been investigated, has been found to vary from ½ to 3% of the coal consumed - possibly ¾% is the correct average - which loss, if figures up theoretically, will be found to agree very closely with the effected saving in fuel values wherever the gasification method of fuel consumption has been installed.

Solid matter from smoke that had been precipitated on building has been found to contain as much as 40% carbon, 4% sulphuric acid. The balance was made up of mineral matter, hydrocarbons, water, etc., the evil effects of which can be well understood.

A further loss is also to be found in the escape of combustible gases that may cause a total value loss of as much as 30%. Stack losses in Western Pennsylvania are found to be 14%; fuel losses in ash, radiation and other sources amount to 16%; one boiler horse power hour has been found to require 4.6 lbs coal, whereas it is possible to generate same 3.6 lbs., so that there is room for much economical improvements in manipulation and installations.

Furthermore, for the purpose of definitely stating wherein the chief loss of fuel values occurs, it can be said authoritatively that the result of a great number of carefully made analytical determinations on the chimney gases of a large number of various installations, that with the production of smoke is to be found the greatest fuel loss, and it follows that the practical avoidance of smoke means the burning of the fuel to the best possible advantage.

The above tests cited conclusively proved that the chief losses in combustible gases occurred from the voiding into the atmosphere of carbon monoxide gas; that there was also a small loss of hydrogen and methane; that where the chimney gases were clear, no loss occurred from carbon monoxide, hydrogen or methane. So that, laconically speaking, "Stop smoking and save money" is an excellent motto when practically applied.

Again, that the presence of CO_2 in the voided chimney gases was not such an unfailable index of the waste or economy being made in the consumption of the fuel, as has often been stated, on the contrary, the percentage of CO is the better guiding factor. It might be pointed out that the percentage of O in clear chimney gases varied between 9.75% and 13.5%, and that of CO_2 from 8.15% to 9.00%. In smoky conditions accompanied by losses of combustible gases, the O ranged from 1.3% to 8.60% and the Co_2 from 8.75 to 13.25% so that it follows that for smokeless conditions a high O and a low CO_2 percentage are desirable.

The explanation of the cause that may occasion error in computations based on the percentage of CO_2 in the voided gases lies in the fact that in perfect combustion

$$C + 2\,O = CO_2.$$

The preliminary re-action may be $C + O = C'O$ equation (1)

and the final re-action is $CO + O = CO_2$ " (2)

In imperfect re-action, in the zone of combustion, the production of CO_2 may be the chief preliminary re-action whereby an extra atom of O is detrimentally taken up at this preliminary time. The carbon dioxide is deoxidized by the incandescent carbon, thus:

$$CO_2 + C = 2\,CO \quad - \quad \text{equation (3)}$$

giving two molecules of carbon monoxide instead of one as in (1). Then the extra molecule of carbon monoxide may take up another atom of oxygen before being voided as carbon dioxide gas - thus:

$$CO + O = CO_2 \quad - \quad \text{equation (4)}$$

where a second atom of oxygen is detrimentally taken up, so that the final product of voided gases may contain twice as much carbon dioxide as is necessary, whereby heat values are wasted and much smoke produced. Numerous careful analyses of smoky and clear chimney gases can be cited to support this theory. This will hardly meet with the views of high efficiency men, where efficiency is valued by cheap first cost of cheap fuel and as little money spent as possible in cheaply feeding the cheap fuel into the cheap installation, whereby the saving that is apparently effected inures to their benefit and the loss and damages that result from the same causes are quite widely and uniformly distributed to the people at large in the form of smoke.

In large installations, where a high standard of "technique" is in order, these losses have been discovered and remedied. A great many more fuel consumers would do likewise were they in-formed as to their losses. Again, small consumers of fuel would find no profit in attempting to save their small losses, and for these ways and means must be found that will meet the imposed requirements, and then they must be compelled to live up to these requirements.

The use of briquetted form of fuel will also play an important part under this heading in the prevention of smoke and attention cannot too strongly be called to the importance of this form of fuel as an effective weapon in the smoke prevention campaign being waged in all large cities.

The use of coke, cheap gas, electricity and power from central power stations can all be utilized in their various localities respectively as economic conditions permit.

Kilns

Powdered fuel has been found to give entire satisfaction in various kinds of kilns.

Engines

Owing to the conditions under which engines are worked, the smoke abatement phase in this class is a different problem. The use of proper kind of fuel - briquetted- has so far given very satisfactory results. The magnitude of the undertaking and the difficulties that beset the solution can be somewhat explained by stating that the consumption of fuel under this heading is equal to 20% of all the coal, both bituminous and anthracite, mined in the United States, and the rate of consuming said fuel is about ten times as fast per grate area as in ordinary steam boiler practice. Financially represented, the railroad fuel bill amounts to about 14% of the operating expenses, or 8% of the gross earnings.

Under this division, where the plants are of sufficient

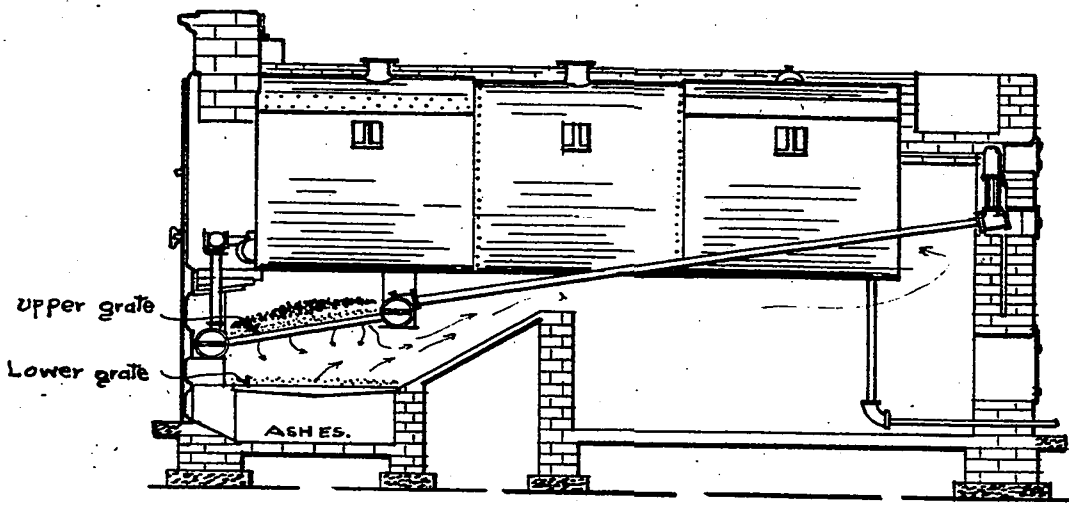


FIG. D HORIZONTAL-TUBULAR-SETTING.

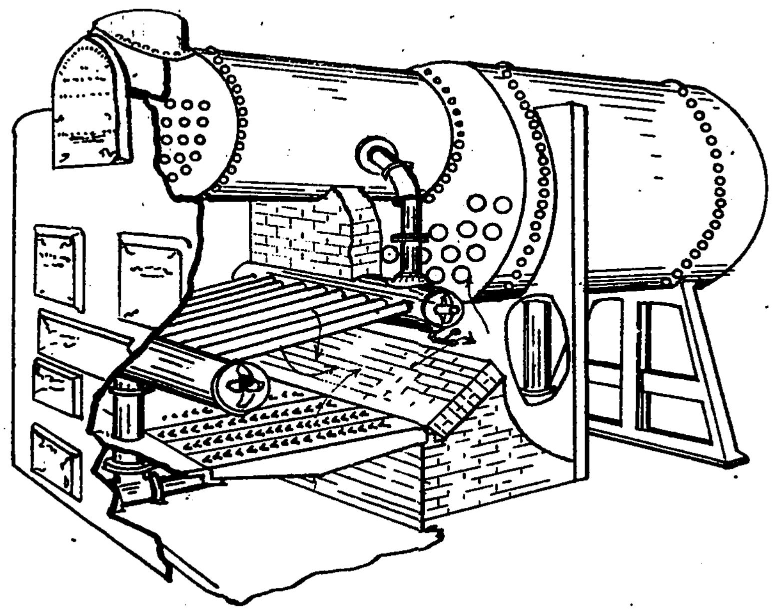


FIG E DOWN-DRAFT BOILER-FOR SMALL-PLANTS

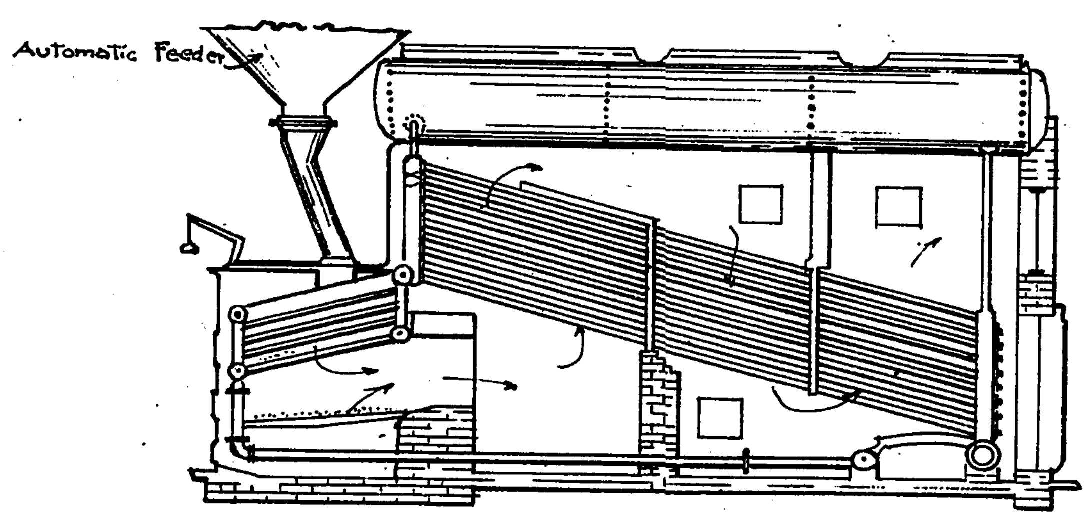


FIG. F - BABCOCK-WILCOX-TYPE-SETTING-GRAVITY-FEED..

size whereby competent stokers are in constant attendance, underfeed stokers enable the consumption of fuel practically without smoke, but 2.4% being produced. The saving in large plants can amount to 30% - 40%; in small size plants, 20% - 30%. In smaller plants, where for various reasons it is not desired to install stokers, the use of the gasification method of consuming fuel, as embodied in the down-draft system, is to be recommended. Fig. D - E - F shows the application of same to various forms of steam boilers.

As aforestated, in France, where 110 different forms of smoke consumers were thoroughly tried during a period covering three years, and in which no first prize was awarded, the third prize was given to the down-draft system, the recovery of the fuel efficiencies being extremely satisfactory, and, though the apparatus was not absolutely smokeless at this time, improvement enables this system to keep well within the imposed limits of smoke production.

The down-draft attachment can be attached to most any boiler installation and in operation is the simplest possible method, in its class of smokelessly consuming fuel. The cheapest labor obtainable, that is permissible, in this class of work is competent to attend this installation. The time required in attendance is also the least possible The cost of the fuel for a building 56 feet wide and 300 feet long, comprising two stories and a basement, during the coldest weather, is 95¢ to $1 a day. The labor in attending the boiler is performed by the janitor.

A comparison of the first cost of this installation as against the ordinary boiler is exemplified as herewith:

Cost of 60 h.p. ordinary boiler	- $500	per h.p. =	$8.34
Down-draft attachment	- 375		
Total cost of down-draft installation	- $875		
With down-draft attachment, boiler gets a 90 h.p. rating = cost per h.p.		=	9.71
Extra cost for the practical smokeless consumption of fuel per boiler h.p.		=	1.37

Part III.

NOXIOUS FUMES resulting from smelting, chemical and all other allied industries.

Under this heading is found the most dangerous and difficult problem of the smoke nuisance, the solution of which has baffled the skill of the scientific and practical chemist and metallurgist, the world over.

Smelting operations of various kinds are chiefly concerned in this part, inasmuch as the fumes that escape are poisonous to animal life and destructive to forests and fields.

The chief deleterious constituents of the fumes are arsenic, sulphur trioxide and sulphur dioxide. The small amounts of lead, copper and zinc, etc. that may escape have not apparently done any harm.

Arsenic, being easily volatilized, is evolved and settles on the vegetation, is consumed by live stock with fatal results especially to sheep, if wet weather is prevalent, or if the sheep are traveling, as soon as they reach a watering place.

Small amounts of arsenic, while not instantly fatal, so decrease the resisting power of the sheep to other diseases that the primary cause of death can well be attributed to the poison. Very small amounts of arsenic are given to horses to improve their coats and make their hair glossy but otherwise arsenic is fatal to both horses and live stock.

Sulphur trioxide with its avidity for water, thereby forming sulphuric acid, has been found to be responsible for the death of thousands of wild ducks in Utah, in the United States, causing inflammation of the alimentary tract. Vegetation of all kinds is most seriously injured by sulphur trioxide.

The aforementioned deleterious constituents of smelter fumes are termed mechanical impurities, inasmuch as mechanical means such as bag houses have been able to eliminate them quite satisfactorily, although sulphur trioxide is given a treatment with zinc oxide and powdered lime rock before it can be recovered as a mechanical impurity, owing to its tendency to destroy the fabric of the bags. These so-called mechanical impurities in Utah have also been found to be responsible for smoke, fogs and hazy atmospheric conditions. However, sulphur dioxide, which is a colorless fume or gas, is not retained or eliminated in its passage through the bag houses (the cost of the required quantity of lime rock and zinc oxide would be excessive - even provided a combination could be effected), and when emitted from the smelter is dispersed by the air currents throughout the atmosphere for miles around, and in the presence of sunlight is continuously absorbing another atom of oxygen and becoming sulphur trioxide which in turn absorbs a molecule of water and becomes sulphuric acid. The sulphur dioxide can also absorb a molecule of water and become sulphurous acid, which is also very destructive to all vegetation. This sulphurous acid has a tendency to also absorb an atom of oxygen and become sulphuric acid. As a partial remedy, dilution with air has been used, but this does not by any means neutralize the sulphur dioxide. It merely distributes more evenly the damage caused, while affording some relief to nearby life and vegetation.

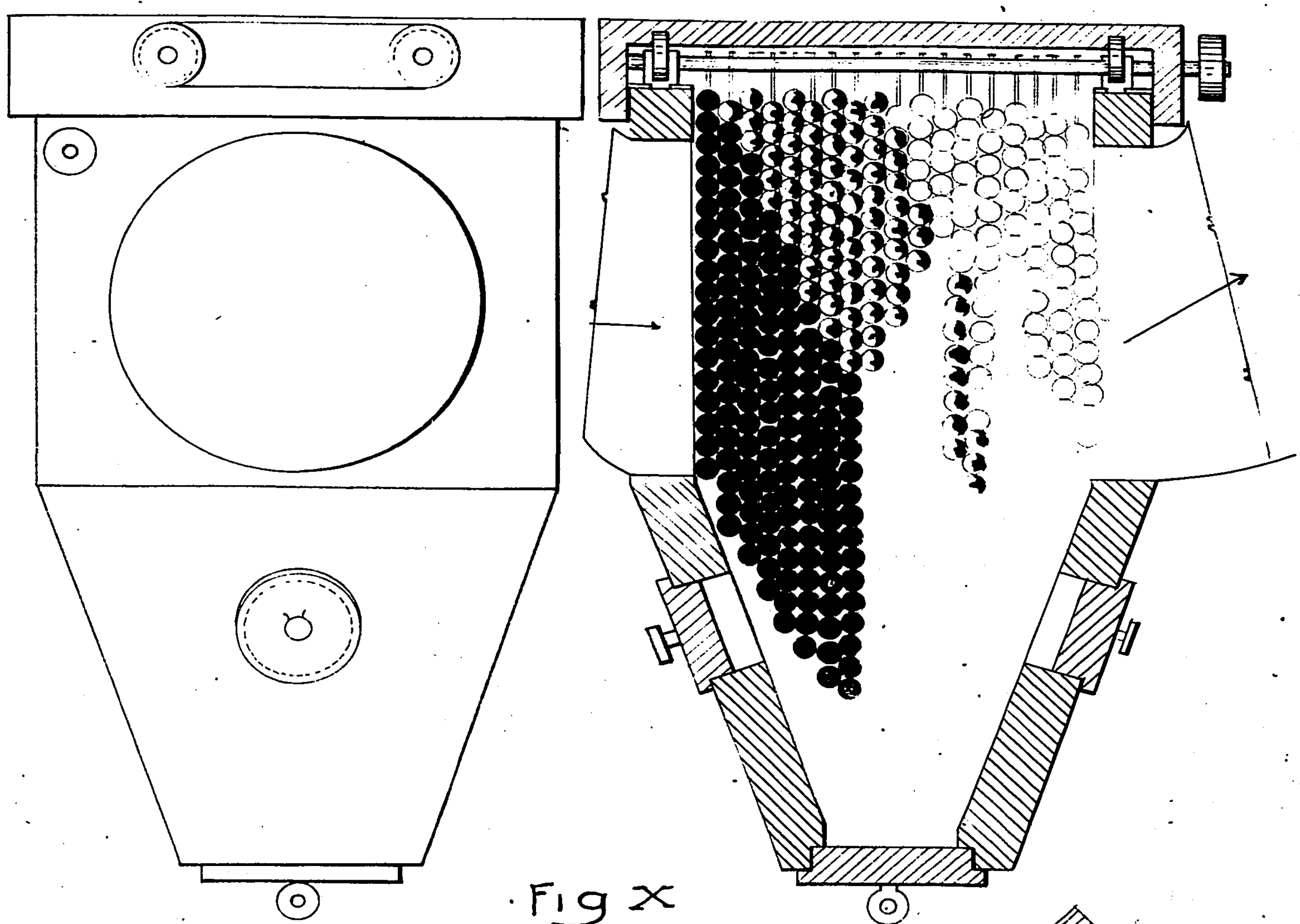


Fig X

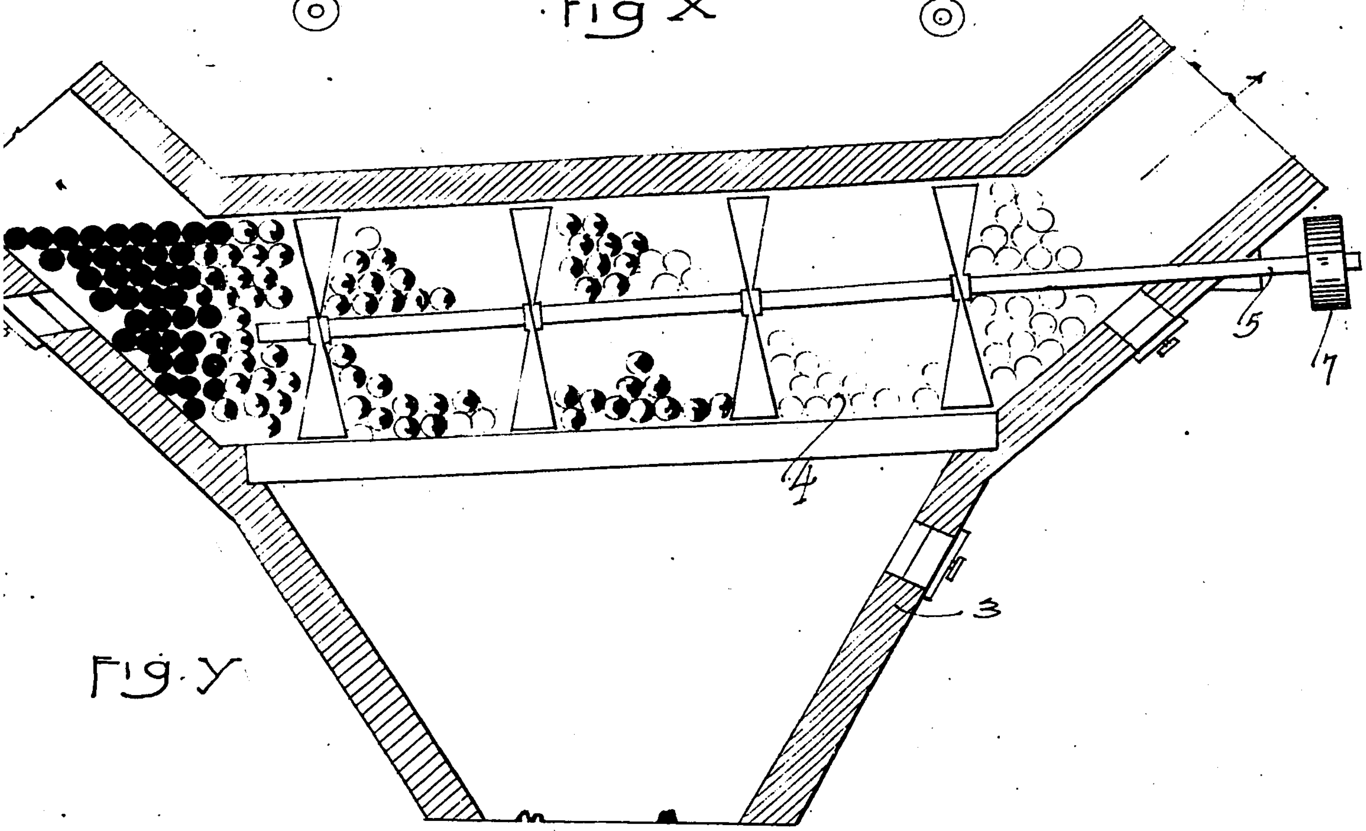


Fig. Y

Thus far, no strictly mechanical method has been found that will satisfactorily and financially overcome the sulphur dioxide nuisance. Hence, it is termed a chemical impurity and recourse must be had to one of the following methods of overcoming same.

1. Neutralizing with milk of lime or moist lime rock.

II. Production of sulphuric acid.

These two methods would be limited by financial reasons, although both could be employed even at some financial loss if the main industry, itself, was sufficiently profitable.

III. Utilization of the fumes for the purpose of extracting valuable metals from various ores.

IV. Reduction of the fumes and recovery of their sulphur content.

Herein lies, in all probability, the scientific and financial solution of the problem, as proposed in III and IV. Either of the two modifications of the mechanical acid smelter fume filters, X and Y, can be used.

Style X, page   is described as follows:

Balls made of any suitable material such as clay, glass, or other acid resisting material, are strung on slender rods and hung in the flue in the path of the smoke. This retards the velocity of the smoke and also cools same, and results in the precipitation of whatever mechanical impurities the smoke contains. The flue should be several times as large where the filter is interposed, owing to the spaces taken up by the balls. The size of the balls and their distances apart and the length of the filter will be determined by the nature of the smoke being handled. The flue can be of any shape. and the supports for the rods holding up the balls are hung on a shaker bar, so that by suitable means, from time to time, the rods and balls are given a shake, which will cause the mechanical impurities to fall down into a hopper which constitutes the bottom of the flue and from which any accumulation can be withdrawn.

The rods on which the balls are strung, project down into the hopper a short way, in order to compel the passage of the smoke through the balls.

Filter, Style Y, is composed of Greenland pebbles or clay balls of suitable size, slowly traveling down an incline grate and are returned at the top. Within the body of the filter, the fumes are drawn through these pebbles at a different direction from that in which the pebbles travel. Hence the effect is very perfect. Hoppers under the grate collect the impurities and enable same to be easily withdrawn and sent to the smelter for the recovery of any values contained therein.

The annexed copy of U. S. Patent #1085712, granted me, February 3rd, 1914, describes the invention and illustrates a perpendicular application of the principle.

The mechanical purification of the fumes is important, otherwise the chemical process will be incomplete and the sulphur recovered very impure. The fumes mixed with hydrogenized hydrocarbon gases from the hydrogenizer, E, are led through the cold coke 20- into the moleculizer, B.

The object of the cold coke is to prevent a flareback of the flames and avoid a possible explosion, although same can be guarded against by taking the same precautions as when handling a gas producer.

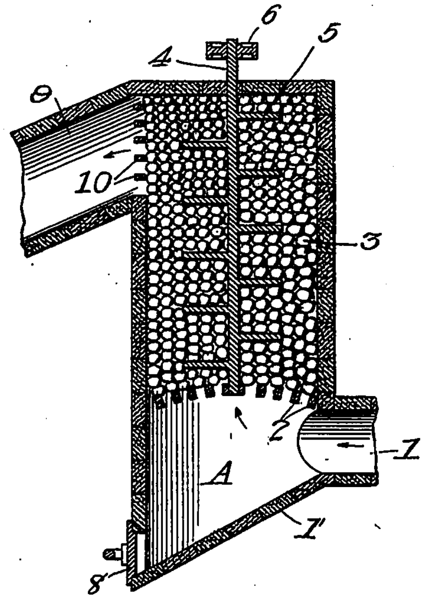
The coke in the moleculizer, B, is kept at the proper temperature from bright red up to 1000° C., depending on the fumes being treated and the results desired. The coke takes

C. S. VADNER.

APPARATUS FOR ARRESTING SMELTER FUMES AND RECOVERING THEIR VALUES.

APPLICATION FILED FEB. 10, 1913.

1,085,712. Patented Feb. 3, 1914.



Witnesses: *Inventor:*

UNITED STATES PATENT OFFICE.

CHARLES S. VADNER, OF SALT LAKE CITY, UTAH.

APPARATUS FOR ARRESTING SMELTER-FUMES AND RECOVERING THEIR VALUES.

1,085,712. Specification of Letters Patent. Patented Feb. 3, 1914.

Application filed February 10, 1913. Serial No. 747,577.

To all whom it may concern:

Be it known that I, CHARLES S. VADNER, a citizen of the United States, and a resident of Salt Lake City and county, State of Utah, have discovered a new and useful Apparatus for Arresting Smelter-Fumes and Recovering their Values.

My invention is one by which smelter fumes may be rendered harmless and thereafter liberated into the atmosphere or be transformed into gases for power purposes. By the use of the apparatus in this specification, I recover the valuable solids contained in the said fumes.

The object of my invention is to so mechanically treat the noxious fumes evolved by various smelting operations that they may be put through the apparatus without rendering the same inoperative by reason of the mechanical impurities that would otherwise be contained therein.

I accomplish this object by means of the apparatus illustrated in the accompanying drawing, in which the figure is a sectional view of my apparatus in which the mechanical filtering is carried out.

The fumes coming from the smelter flues are led through the intake flue 1 into the recovery tower A. Said recovery tower has a sloping bottom 1′ sloping away from the intake flue and above the entrance of the intake flue there is a grate made of chemical bricks 2 set with suitable apertures entirely across the base of the recovery tower. Resting upon the said grate are a number of small hollow iron shells, Greenland pebbles or other spherical bodies 3 of suitable size and character. The openings of the grate 2 and the upper grate 10 are smaller than the diameter of the bodies 3. In the center of the recovery tower is a rotary stirrer 4 having stirring arms 5 at suitable intervals and provided with the pulley 6 or other suitable means for the operation of the same outside of the recovery tower. These shells, pebbles or bodies completely fill said recovery tower, and are prevented from falling into the outlet 9 by the grate 10 which is composed of chemical bricks insoluble by acids, set at suitable intervals across the opening in the said outlet. The fumes percolating upward through the irregular apertures between the shells or pebbles lose all their mechanical impurities, which become disposed in the interstices between the shells or other bodies. The rotary stirrer 4 is rotated by the means provided and by agitating the shells or pebbles in the tower, the mechanical impurities consisting of gold, silver, and other valuable metals are permitted to fall down through the spaces in the brick grate to the sloping floor 1′, thence they may be drawn off through the manhole 8 and returned to the smelter for the recovery of their valuable constituents.

By this apparatus all their mechanical impurities are filtered from the fumes preparatory to their passing onward through outlet 9 into the other gas treatment apparatus.

Having thus described my invention what I claim as new and desire to secure by Letters Patent is:

An apparatus for purifying smelter fumes, comprising a tower provided with a traverse partition wall forming a chamber above and below it, a filtering body, composed of pieces of insoluble solid material in said tower, above said wall, an agitator in the upper portion of said tower adapted to agitate the filtering bodies, and by such agitation to cause the particles of solid matter carried off by the smelter fumes, to drop to the bottom, said partition wall being provided with openings of such size as to permit such solid particles to pass therethrough, but retaining the filtering bodies, and means for the entrance of said smelter fumes below the said partition wall, said tower having an inclined bottom, and means for the removing of the filtered particles from the bottom of said chamber, substantially as described.

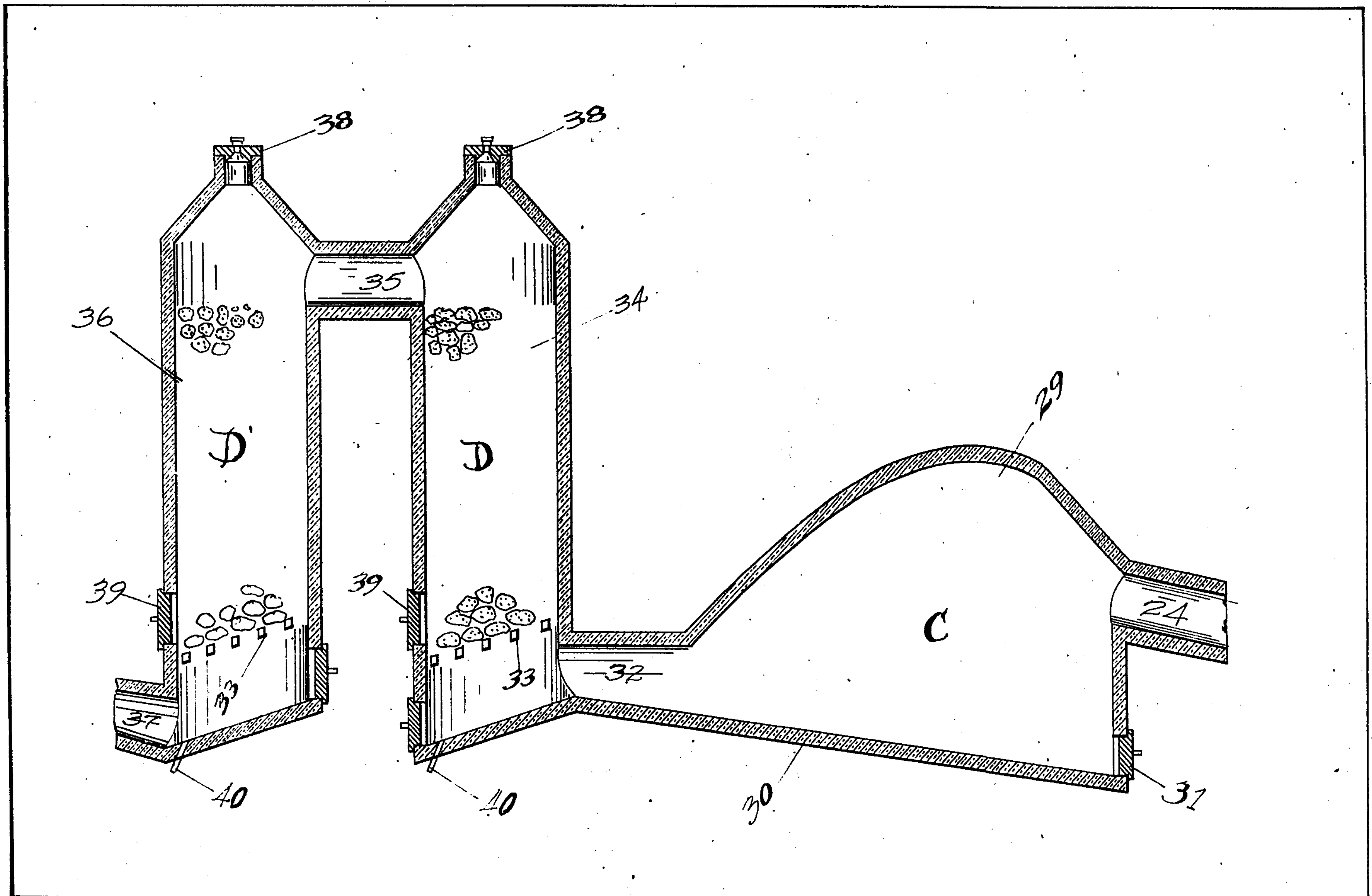
In witness whereof I have hereunto set my hand this 5th day of February, 1913.

CHARLES S. VADNER.

Witnesses:
R. C. FARNOW,
F. B. SCOTT.

practically no part in the reaction, acting as a regulator of the heat and assisting the mingling of the fumes. Some of the coke, however, will be consumed by the free oxygen present. The heat of the coke can be regulated by admission of air or steam at 26. The hydrocarbonaceous gases are cheaply obtained as waste gases from beehive coke ovens, which contain as much as 54%, and when hydrogenized by passing through the hydrogenizer, E, will contain as much as 80% hydrogen, crude oil, tar and other hydrocarbon residues can be used. Care must be taken in all cases to first pass them through the hydrogenizer, E, otherwise the carbon from the decomposition of the hydrocarbons will give trouble in the moleculizer, B. The checker brick chamber, 28, can be built close to B and kept highly heated to decompose any traces of hydrogen sulphide gas escaping from B, or can be utilized to recover the waste heat from the hot gases from B. The reactions taking place in B are described in the patent specifications.

The amount of coal required to produce the coke necessary in most all smelting establishments will also produce about the necessary amount of hydrocarbon gases to reduce the sulphur dioxide and sulphur trioxide evolved, which fumes should be kept as concentrated as possible in order to save the consumption of coke in B by the oxygen of the free air and unnecessary dilution by the inert nitrogen whereby the size of the apparatus is reduced. The amount of hydrogen necessary to effect the reduction is stated approximately above, and absolute figures could only be stated by a knowledge of the composition of the fumes and the magnitude of the operations. The sulphur reduced in B is volatilized and recovered in C. Traces of undecomposed hydrogen sulphide gas are caught in oxide of iron tower, D, said ozide of iron



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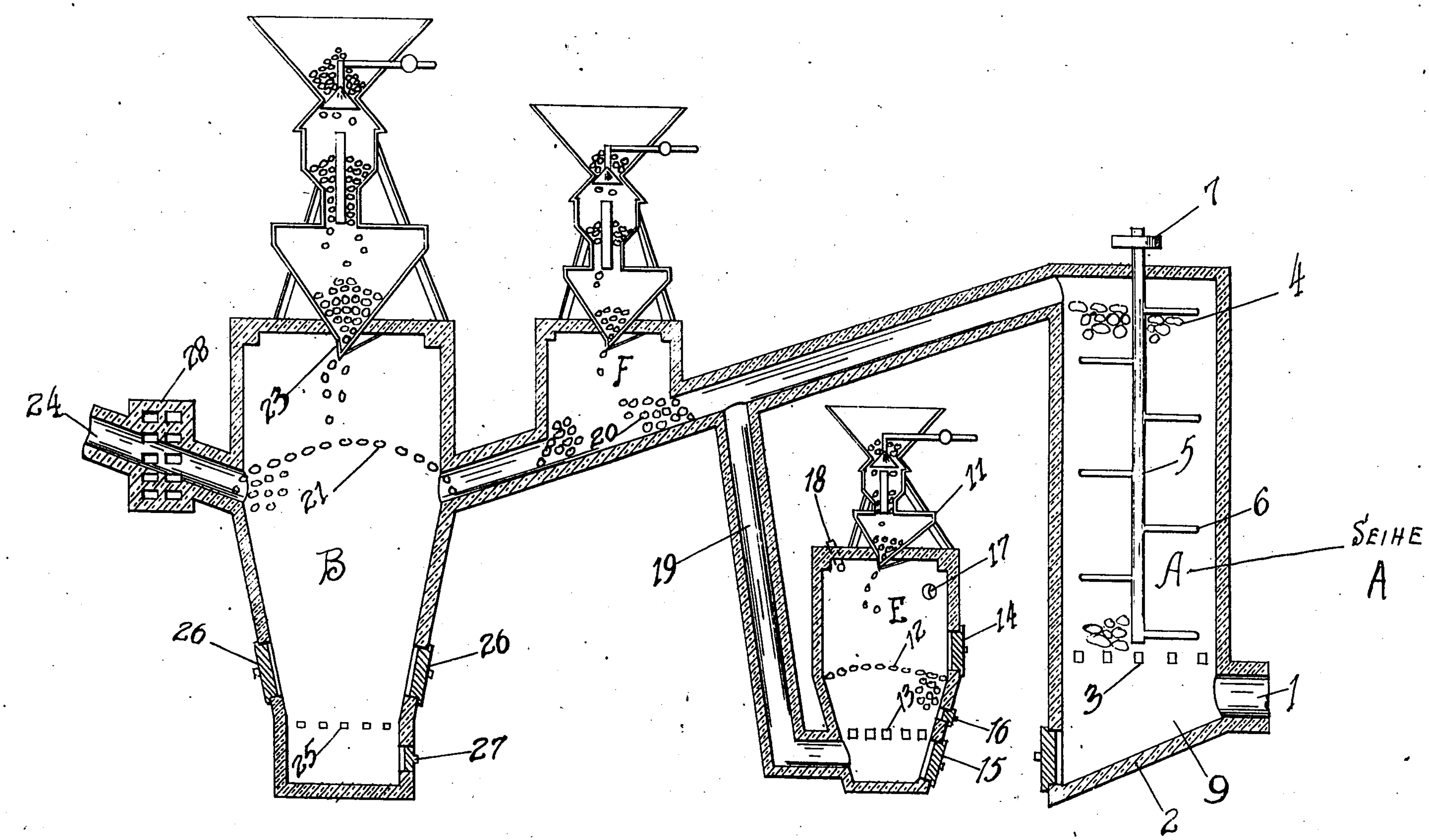

28
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becomes unoperative after being in use for some time, but on exposure to the air, the sulphur can be recovered in a metallic form and the oxide of iron is regenerated again. The gases are drafted through the entire apparatus by a fan of suitable size located at 39, and if these gases are found to have combustible properties, they can be used to generate heat or power by using suitable machinery.

Sizes and dimensions in these operations would be regulated by those of the works to which they would be attached. The body of the mechanical filter, A, should be two or three times as large as the intake flue, I, also the bodies of towers D and D', and likewise the intake and outlet of moleculizer, B.

Respectfully submitted,