# United States Patent [19]

**Osthaus**

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[54] **METHOD OF PRODUCING ELECTRIC ENERGY INCLUDING COAL GASIFICATION**


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[51] **Int. Cl.** ............................................... **C10j 3/00**

[58] **Field of Search** ......... 60/64, 39.12; 48/203, 76; 290/2, 40, 52



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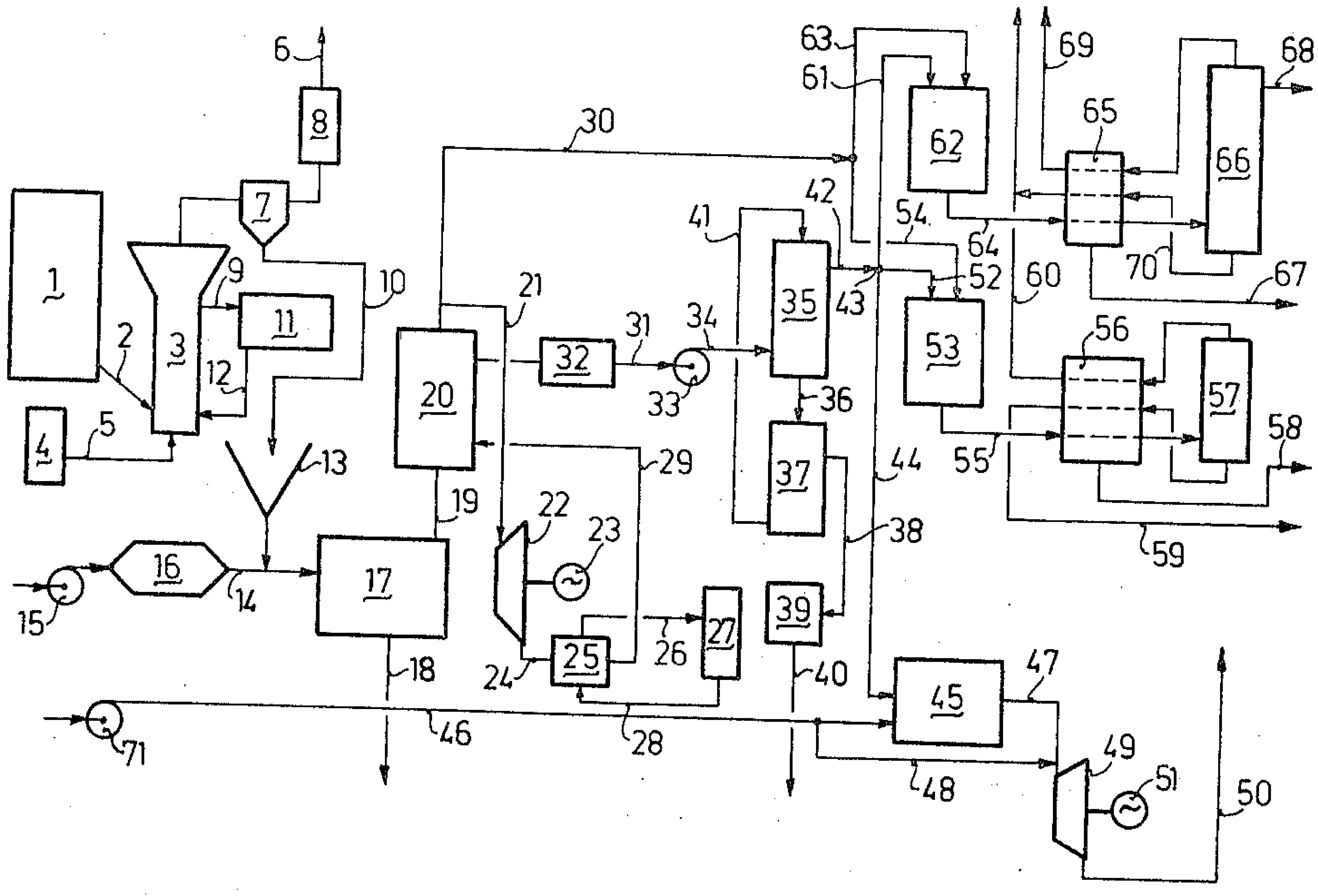
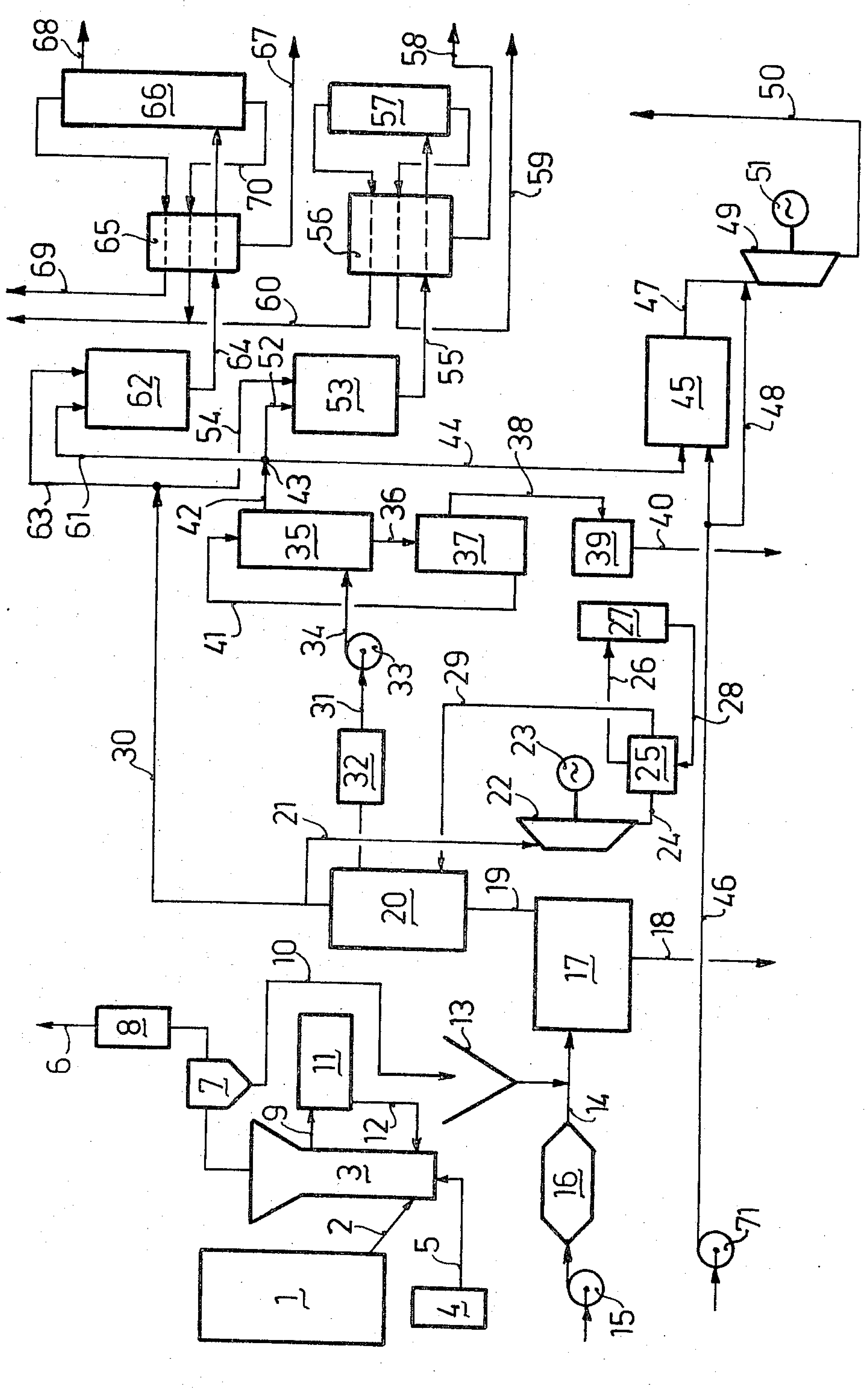
[57] **ABSTRACT**

Chunk coal is comminuted to form coal dust, or existing coal dust is utilized. The coal dust is advanced in concurrent flow with a stream of heated air, and is gasified at atmospheric pressure and at a temperature of substantially 1,500°C. The resulting combustion gases are cooled by admitting them to a waste-heat boiler, to substantially 150°C and concurrently with this cooling effect steam is produced by heat exchange with the gases. At least some of the thus produced steam is utilized to generate electric energy at such times as the electric energy which can be generated with the aid of the steam is sufficient to meet demands. The cooled gases have dust electrostatically removed from them, and are thereupon compressed to a pressure of between 20–50 atmospheres, whereupon they are de-sulphurized. Some or all of the thus de-sulphurized compressed gases are used to generate additional electric energy, but only at such times as the demand for electric energy exceeds the amount which can be generated with the aid of the steam produced by the combustion gases. Any compressed and desulphurized gases which are not used for the production of additional electric energy are subjected to further processing.


**9 Claims, 1 Drawing Figure**

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# METHOD OF PRODUCING ELECTRIC ENERGY INCLUDING COAL GASIFICATION

## BACKGROUND OF THE INVENTION

The present invention relates to a method of producing electric energy, and more particularly to a method of producing electric energy based upon the partial oxidation of coal dust. Still more specifically, the present invention relates to the production of electric energy using hot gases which are obtained by the partial oxidation of coal dust.

It is well known that every producer of electric energy for household, commercial and other purposes is faced with the problem that the energy demand differs at different times of the day. Thus, the highest energy demand of the day may come in the summertime around noon, when a large number of airconditioners and other devices is in operation. During the night when the temperature drops somewhat, less energy will be required for airconditioners, and of course, also for other purposes, since many businesses are closed at night-time and since the household consumption of electric energy also decreases. The producer must be ready to meet both types of demand, that is either the low demand at night (or in another comparable time period when low demand occurs) and the peak demand. On the other hand, he cannot produce electric energy constantly at the peak-demand level, because this type of electric energy cannot effectively be stored. It is hardly necessary to point out that this problem is highly disadvantageous in terms of the economy of electric energy production.

The prior art has made various attempts to overcome the problem. One of these has been to create power grids, where different power-consuming areas are linked with one another, and one area can draw upon extra electric energy of another area. This is effective to a certain extent if the areas have different peak demand times, for instance if they are far apart so that due to an existing time differential, peak demand occurs in the various areas at different times. Thus, an area having a peak demand period can draw upon the excess electric energy of a producer who is associated with the grid and is located in an area where at this same time there is a low demand. However, for various reasons this solution also is not fully effective, and the industry continues to actively seek better solutions, especially solutions which provide improved operating economy.

## SUMMARY OF THE INVENTION

Accordingly, it is a general object of the present invention to provide such an improved solution.

More particularly, it is an object of the present invention to provide an improved method of producing electric energy.

Still more particularly, an object of the present invention is to provide an improved method of producing electric energy by utilizing hot gases obtained by the partial axidation of coal dust.

In keeping with these objects, and with others which will still become apparent hereafter, one feature of the invention resides in a method of producing electric energy, in the steps of advancing coal dust in concurrent flow with a stream of heated air, and effecting its gasification at atmospheric pressure and at a temperature of substantially 1,500°C. The resulting combustion gases



are cooled in a waste-heat boiler to substantially 150°C. and concurrently steam is produced by heat exchange with the gases. At least some of the thus produced steam is utilized to generate electric energy at such times as the electric energy which can be generated with the aid of the steam is sufficient to meet demands. The cooled combustion gases have dust electrostatically removed from them, and are thereupon compressed on a pressure of between substantially 20 – 50 atmospheres, and finally de-sulphurized. At least some of the de-sulphurized compressed gases are used to generate additional electric energy only at such times as the demand for electric energy exceeds the amount thereof which can be generated with the aid of the steam produced by cooling the combustion gases.

To operate with the method of the present invention, the coal dust oxidation installation is so dimensioned that the heat which can be reovered by heat exchange in the waste-heat boiler from the combustion gases produced by the partial oxidation of the coal dust, is at least sufficient to generate that amount of electric energy which is necessary to meet the basic energy demand, that is to produce the amount of electric energy which the producer can sell on 24-hour basis. The gases, however, which produce the steam required for generating the basic amount of energy, are utilized for producing additional electric energy at the peak demand periods, that is to produce the amount of energy which must be added to the basic amount produced by the steam in order to meet the peak energy demand. Evidently, there will be circumstances and/or time periods when it is not necessary to produce additional electric energy, because a peak demand does not exist. Then again, there will be circumstances when the additional energy which must be produced with these gases in order to meet the peak demand, does not require that all of the gases be utilized for energy production. Any gases which are not required for the production of additional electric energy can, in accordance with the present invention, be utilized for other purposes so as not to be wasted. In particular, these gases can be converted into a methane-rich gas, into hydrogen and/or a so-called ammonium-synthesis gas. Two or more of these conversions can be carried out simultaneously, by allocating appropriate parts of the available gases to the different conversion methods. It is evidently also possible to convert the gases for other purposes, which will suggest themselves to those skilled in the art.

The coal dust required for the present invention can be produced by a so-called comminuting or grinding drying process, which will be described subsequently. In this case, chunk coal is converted into coal dust. There will, however, be many instances when sufficient coal dust is already available as a waste product of normal coal production, particularly if the coal is produced under certain production conditions. Evidently, if the coal dust is already available, it need be merely dried, not comminuted.

An essential feature of the present invention is the fact that the gasification or partial oxidation of the coal dust is carried out at normal pressure, that is at atmospheric pressure. Heretofore, it has always been an aim of the industry to operate coal dust gasifying equipment at increased pressure levels, during gasification of the coal at temperatures of approximately 1,500° C. which are above the slag melting point. However, the introduction of the quantities of which are required for carrying out the method of the present invention, for instance on the order of 500 tons per hour, creates certain problems if the gasification equipment operates at super-atmospheric pressure. It is for this reason, that the present invention proposes to subject the gases produced during the coal dust gasification to an electrostatic dust-removal operation, and thereupon to compress them at pressures of between substantially 20 – 50 atmospheres. Since the present invention requires the use of air in conjunction with the coal dust during the gasification of the latter, the advantage which exists in certain prior-art gasification proposals, namely to operate the gasification equipment at higher pressure levels in order to eliminate or reduce the necessity for subsequent compression of the gas, does not exist in any case, but its absence is far outweighed by the advantages obtainable with the present method.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of opertion, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWING

The single FIGURE is a flow diagram which illustrates, by way of example, how the present invention operates.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

The example illustrated in the drawing is based upon the conversion of chunk coal into coal dust, that is, it assumes that coal dust is not already available in dust form or is not being used in the initial step. The term chunk coal used herein should be understood not merely to refer to large-size coal pieces, but also to relatively coarse granules of coal as opposed to mere coal dust.

With the aforementioned comments in mind, it will be seen that the coal to be gasified, either soft coal or hard coal, is admitted from the coal bunker **1** through a conduit **2** into a drying tube **3** the upper end of which is divergent as shown, and which operates as an airdryer. At the same time, coal dust is combusted in a furnace or combustion chamber **4** and the hot combustion gases are admitted at approximately 800°C. temperature through the conduit **5** into the lower end of the conduit **3**, to rise herein. The coarse coal particles admitted from the bunker **1** are removed from the rising gas stream at the upper diverging part of the conduit **3**, whereas the fine coal dust which is carried along by the upwardly moving gas stream enteres the cyclone **7**, where it is separated from the gas stream in dry condition. The vapors which develop during this drying operation for the coal dust are withdrawn through the conduit **6**, after they have passed through a cooling and scrubbing stage **8**.

The coarse coal particles which have been retained in the upper divergent part of the conduit **3**, are admitted via conduit **9** into the grinder or comminuter **11** in which they are comminuted to form coal dust. This dust is returned via conduit **12** into the lower part of the drying conduit **3**. As this takes place, the coal dust which has been recovered and returned in the cyclone **7** flows via the conduit **10** to an intermediate storage bunker **13**, from where it is fed into the conduit **14** through which the air flow that is required for the desired coal dust gasification.

This air has previously been pressurized in blower **15**, and pre-heated to approximately 600° C. in an air heater **16**. The mixture of air and coal dust enteres the gasification unit **17** which is of completely conventional construction, as described in Ullmann's Encylklopadie de Scchnischen Chemie Vol. **10, 1958,** page 412–413 (Berlin-Mandren) and is gasified therein at a temperature of approximately 1,500° C. The molten slag which results during gasification is withdrawn in molten condition through the conduit **10**, and is subsequently subjected to a granulation step. Since the gasification takes place at normal pressure, that is at atmospheric pressure, the unit **17** must be appropriately large-dimensioned. To retard as much as possible the heat energy radiation, the unit **17** must be provided with an effective thermal insulation, and it will be noted that the wasteheat boiler **20** is located not in the unit **17** itself, but is arranged separate from the same.

Assuming, by way of example, that the unit **17** receives 100 tons of coal dust per hour, then during each hour approximately 400,000 $Mm^3$ of a gas are produced, having the following composition:

3.4 % by volume $CO_2$,
**26.0%** by volume $CO_2$,
9.4% by volume $H_2$,
0 % by volume $CH_4$,
61.0% by volume $N_2$,
0.2% by volume of sulphur compounds.

This gas if of course hot. It is admitted via the conduit **19** into the waste-heat boiler **20**, where it is cooled from approximately 1,500°C. to approximately 150°C. The heat exchange which makes this cooling possible, results in the production of high pressure steam at a pressure of 120 atmospheres, and a temperature of 520°C. This steam is furnished via the conduit **21** to a turbine **22** which is coupled with a generator **23**, capable of producing the normally required amount of electrical energy, that is the amount of electric energy which can be sold on a 24-hour basis. This, in other words, is the amount of energy that can be sold around the clock.

The steam which has been expanded and cooled in the turbine **22**, is furnished via the conduit **24** into the condenser **25**. Cooling water required for the operation of the condenser **25** is supplied to the same via conduit **28** from a cooling tower **27**, and after it has been heated up in the condenser **25** it is recirculated to the cooling tower **27** via a conduit **26**. The condensate produced by condensing of the steam in the condenser **25** is returned via the conduit **29** into the waste-heat boiler **20** for the production of additional steam.

If the amount of high pressure steam produced in the boiler **20** is not required in its entirety for driving the generator **23** via the turbine **22** in order to produce the normally required amount of energy which can be sold on a 24 hour basis, that is the base amount of energy, the excess steam can be vented via the conduit **30** and supplied to the subsequently following gas processing stations, which will now be described.

The gas, which has been cooled in the boiler 20 to a temperature of approximately 150°C., is vented from the boiler **20**, and supplied to an electrostatic dust separator **32**, wherein it is freed of dust particles. From there, it passes via the conduit **31** to the compressor **33** where it may be compressed to a pressure of between substantially 30–50 atmospheres, depending upon requirements. In the present example it is assumed that a pressure of approximately 30 atmospheres is sufficient. The thus compressed gas is then passed on through the conduit **34** into the de-sulphurizing unit **35**, where it is scrubbed of the sulphur compounds, particularly the $H_2S$, by treating it in known manner with a known solution or substance, which flows through the unit **35** in downward direction, that is in counterflow to the gas which rises upwardly through the unit **25.** During this flow, the solution becomes enriched with the sulphur compounds, and is discharged into the scrubber **37** via the conduit **36** where it becomes regenerated. Scrubbed-out $H_2S$ is supplied via the conduit **38** into the Claus oven **39**, where it is combusted to form elementary sulphur which is vented out of the installation via the conduit **40.** During this time the regenerated solution is pumped out of the scrubber **37**, and via the conduit **41** back to the top of the unit **35.**

At this point in time, the compressed and desulphurized gas is advanced via the conduit **42** to the distributor (e.g. valve) **43**, where it can be split up into partial streams. That amount of gas which is to be used for producing additional electric energy to meet peak energy demand, is advanced via the conduit **44** into a pressure burner **45** in which it is combusted at for instance approximately 1,500° C and 30 atmospheres pressure. The combustion air required for this purpose is pressurized in the device **71** and blown under pressure through the conduit **46** into the unit **45.** The hot combustion gases produced in the unit **45** are vented via the conduit **47**, and are admixed with compressed air which is supplied by a bypass conduit **48.** This results in a cooling of the thus-created mixture to approximately 820°C., and the thus produced cooled mixture is admitted to the turbine **49** which it drives, during which operation it becomes expanded. The expanded gas issues from the turbine **49** at a temperature of approximately 150°C., and is vented via the conduit **50** to the chimney. The turbine **49** is coupled with a generator **51** which produces the necessary amount of electrical energy to meet the peak demand, that is, it produces an amount of electrical energy equal to the difference between the peak demand and the amount of energy produced by the generator **23.**

Any compressed and de-sulphurized gas which is not required for producing electric energy via the generator **51**, can be processed for different purposes and in a different manner. In the illustrated embodiment, it is split up at the point **43** into two partial streams, one of which is supplied via the conduit **52** into a methane producing installation **53**, in which the gas is converted at a temperature of approximately 400° C. in the presence of an appropriate catalyst, for instance an iron catalyst well known in the art, to form a methane rich gas. The water vapor necessary for this conversion can be supplied via the conduit **54** which communicates with the unit **53** and with the conduit **30.** If no vapor or steam can be supplied via the conduit **30**, then it is of course necessary to derive the vapor or steam from an external source. The methane-rich gas produced in the unit **53** and vented therefrom through the conduit **55**, has the following composition:

22.8% by volume $CO_2$,
9.7% by volume $CH_4$,



67.5% by volume $N_2$,
traces of $H_2$, CO, and $H_2O$.

This gas which has been thus produced is admitted into a heat-exchanger **57** where it is cooled in heat exchange with a gas stream which comes from a gas separating unit **57.** $CO_2$ is separated from the gas and vented out of the installation via the conduit **58.** In the gas separating unit **57**, $CH_4$ and $N_2$. $Ch_4$ are withdrawn via the conduit **59** which passes the heat exchanger **57.** $N_2$is similarly withdrawn via the conduit **60.**

The second partial stream of compressed and desulphurized gas which is branched off at the point **43**, is admitted via the conduit **61** into a converting unit **62** which receives steam from conduit **30** via a conduit **63** or via an external source of steam. The gas is converted in known manner, that is either by way of high temperature conversion or low temperature conversion, by contact with catalysts which are known in the art. The gas which is produced by conversion and which is vented from the unit **62** via the conduit **64**, has the following composition:

23.4% by volume $CO_2$,
28.2% by volume $H_2$,
48.4% by volume $N_2$,
traces of CO and $H_2O$.

This gas is passed via the heat exchanger **65** into a gas separating unit **66.** In the heat exchanger **65** it undergoes cooling, resulting in a separation of $CO_2$ from the gas, which $CO_2$ is withdrawn via the conduit **67.** The gas which is derived after treatment in the installation **66**, and which is withdrawn therefrom via conduit **68**, contains $N_2$ and $H_2$ in a ratio of 1 : 3; this gas is therefore suitable for further processing to produce an ammonium-synthesis gas. Excess $H_2$ is withdrawn via conduit **69** and heat exchanger **65**, whereas excess $N_2$ is withdrawn via conduit **70** and heat exchanger **65**, to be furnished to the conduit **60** and united with the $N_2$ which is already present in the same.

It should be clearly understood that no attempt has been made in the flow diagram to illustrate or describe components, equipment, or processes which are already well known to those skilled in the art, for instance, the construction and operation of the heat exchangers, gas separating units, or the like. Similarly, such necessary but conventional parts of the installation as valves, pumps and the like, whose presence and location will be readily apparent to those conversent with the field have not been shown or described.

The present invention presents a method of producing electric energy which permits a heretofore unequaled flexibility in the production of electric energy that is a flexibility in the accommodation of the energy production to peak and off-peak demands. Moreover, the economy of energy production is not merely significantly improved over the prior art, but is guaranteed, because of the possibility afforded by the present invention, of converting the gas not required for the production of additional electric energy into other useful and economically valuable products, as part of the energy-production cycle.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of applications differing from the types described above.

While the invention has been illustrated and described as embodied in a method of producing electric energy, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims:

**1.** In a differential-cycle method of producing electric energy for peak and off-peak demand conditions, the steps of advancing coal dust in concurrent flow with a stream of heated air, and effecting its gasification at atmospheric pressure and at a temperature of substantially 1,500°C; cooling the resulting gases in a waste-heat boiler to substantially 150°C and concurrently producing steam by heat exchange with said gases; using only the thus produced steam to generate electric energy at such times as the electric energy which can be generated with the aid of the steam is sufficient to meet off-peak demands; removing dust electrostatically from the cooled gases, thereupon compressing the latter to a pressure of between substantially 20 – 50 atmospheres, and finally desulphurizing the compressed gases; and using at least some of the de-sulphurized compressed gases to generate additional electric energy only at such times as the peak demand for electric energy exceeds the amount thereof which can be generated with the aid of the steam produced by cooling said combustion gases.

**2.** In a method as defined in claim **1**, the preliminary step of producing said coal dust by subjecting coal chunks to a grinding and drying operation.

**3.** In a method as defined in claim **1**; and further comprising the step of converting that amount of the compressed and de-sulphurized gas which is not required for generating of said additional electric energy, into hydrogen.

**4.** In a method as defined in claim **1**; and further comprising the step of converting that amount of the compressed and de-sulphurized gas which is not required for generating of said additional electric energy, into ammonia-synthesis gas.

**5.** In a method as defined in claim **1**; and further comprising the step of converting that amount of the compressed and de-sulphurized gas which is not required for generating of said additional electric energy, into hydrogen and ammonia-synthesis gas.

**6.** In a method as defined in claim **1**; and further comprising the step of converting that amount of the compressed and de-sulphurized gas which is not required for generating of said additional electric energy, into a methane-rich gas.

**7.** In a method as defined in claim **1**, wherein the step of using said steam to produce electric energy comprises driving a turbine with said steam, and driving a generator with said turbine.

**8.** In a method as defined in claim **1**, wherein the step of using said compressed and de-sulphurized gases to generate electric energy comprises admitting said gases under pressure into a combustion chamber, combusting the gases to produce gaseous combustion products at substantially 1,500°C, admixing pressurized air with said combustion products to form therewith a mixture having a temperature of substantially 820°C, and driving with said mixture a turbine which is coupled with a generator.

**9.** In a method as defined in claim **1**; further comprising using that amount of the steam which is not required for generating of electric energy, in one of the succeeding steps.

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