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# INNOVATIONS IN COKEMAKING AND THE ROLE OF THE CANADIAN CARBONIZATION RESEARCH ASSOCIATION

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# INNOVATIONS IN COKEMAKING AND THE ROLE OF THE CANADIAN CARBONIZATION RESEARCH ASSOCIATION

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## ABSTRACT

Coke is the single most costly item in steelmaking. Recent innovations in cokemaking have been directed towards reducing this cost whilst simultaneously improving coke quality and expanding the range of coals used in the process. It is also important to meet increasingly stringent environmental legislation.

Improvements in coke quality have been achieved with novel blend selection procedures, by charge density control using both selective pulverization and partial briquetting and by use of modifying additives.

The Canadian Carbonization Research Association provides a focus for Canadian cokemaking research which has demonstrated these technologies in a series of pilot scale experiments.

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## INTRODUCTION

The Canadian steel industry is currently the envy of most of it's counterparts elsewhere in the world. It is operating at virtually 100% of capacity; most other nations are in a prolonged period of under-capacity operation. The high production levels of 1978 reflect a real production rather than a stockpiling exercise.

The industry in Canada has always been oriented towards a domestic market although it must be recognized that the decrease in "$ Canadian" value has improved the export potential during the past year.

One of the reasons for this current international envy is the importance which the industry has historically attached to innovation and the investment capital that has been continuously recycled to maintain the industry in the forefront of the steel-making state of art.

This inventiveness has been applied across the entire range of processes found in a modern integrated steelworks. It was conceived and nurtured by the industrial pressures to be competitive in the national and international market place. More recently other forces have helped to sustain its life. Chief amongst these have been the twin pressures to improve and protect the environment and the developing pressure to conserve energy in all industrial applications.

All of these pressures compete for available capital to realize their objectives. Environmental control may demand capital with unattractive returns on investment; energy conservation is usually financially more attractive but still may not meet current investment requirements.

Coke making is an integral part of the steel-making process and has not been neglected in the inventive thrust of the industry. It has its own impressive record of response to the commercial, environmental, and energy pressures that affect the industry.

## THE QUALITY OF BLAST FURNACE COKE

Coke production throughout the world is directed towards use in the blast furnace which currently consumes about 350 million tons of the global production of 370 million tons. This end use provides the main impetus for innovative cokemaking.

A typical coke rate in the blast furnace is 7000 Btu/coke per lb of finished steel - this translates to approximately 970 lb of coke per ton of steel. In order that this coke consumption shall be reduced or that the coke will be produced more cheaply the coke characteristics must be defined. The method of achieving these characteristics leaves room for innovation.

In a blast furnace the coke must act as both a heat source and a reductant source; it must also physically support the charge and provide a controlling permeability to govern the flow of gases through the system. In fulfilling these functions it should neither make a major contribution to the slag burden nor introduce unnecessary fluxes. It must not introduce sulphur which could end up in the molten metal.

These requirements have been translated into a general coke specification for modern blast furnace use.

| | | |
|---|---|---|
| Ash | % | 8.0 (upper limit) |
| Volatile matter | % | 1.0 " " |
| Sulphur | % | 0.7 " " |
| Alkali ($Na_2O + K_2O$) | % | 0.2 " " |
| Phosphorous Pentoxide | % | 0.27 " " |
| | | |
| Stability index * | | 55: (lower limit) |

* The stability index is a strength indicator which describes the coke's ability to resist degradation during handling and use.

In the historic development of cokemaking these properties were originally achieved by use of a single medium volatile bituminous coal. The coke oven operator was, however, always at the mercy of seam variability.

The luxury of a single seam source in cokemaking no longer exists. Current practice is to blend coals to generate the desired ( or enhanced) coke quality. The use of a blend always allows a wider tolerance to variation in the quality of one component. Most Canadian facilities use two or three component blends although complex blends of more components are used elsewhere. The clear prerequisite of a successful blending quality control program is a detailed knowledge of the coal pyrolysis process which can be built into the coal selection procedures prior to attempting blending.

Because of these quality requirements it can be seen that innovation in cokemaking will fall into the same two categories that occur in most process industries. The first is the innovative concept of how and why certain things happen, the second is the engineering innovation that allows the operator to control and direct what will be allowed to happen.

This first category is one for research and development which allows the effect **of (for example)** charge density, selective pulverization, partial briquetting, coal additives on coke quality to be clearly established. The second category is one of engineering which focusses on the design and operation of coke ovens to ensure ease of coal and coke handling with effective emission control, by-product recovery and energy conservation. Although the categories are described as being different the boundaries are indistinct.

For example, the use of a dry quenching technique in cokemaking will overlap the areas of emission control, coke quality and energy conservation. It is unlikely that dry quenching could be justified on economic ground unless this overlap existed.

## COKEMAKING COALS

Bituminous coals for cokemaking must show an ability to soften under the influence of heat and to remain plastic throughout a temperature range prior to resolidifying to produce a strong compact coke. Characteristic behaviour is shown in Figure 1 **(1)**. Both the degree of plasticity and the temperature at which the maximum plasticity occurs are important parameters used in defining the coking potential of coals which will be used alone or in blended combinations.

Plasticity measurements at elevated temperatures are made using a Geissler plastometer on a routine basis for most cokemaking feedstocks. Reflectance measurements, which define the coal surface response to incident light, can be used to characterize different components in a coal structure. The twin measurements, plasticity and reflectance can provide one method of classifying and selecting coals for cokemaking purposes.

Figure 2 shows a correlation between maximum Geissler fluidity and coal reflectance that has been developed from operating data (2). The field of coal characteristics that are suitable for use in conventional Scot type ovens is seen to be small. A few Canadian coals from North Eastern British Columbia fall within the specification field illustrated. Others lie well beyond the "ideal" specification.

The prime objective of cokemaking technology is to move around in the framework of Figure 2 and use existing coals with apparently unsuitable (or at least non-ideal) properties. Judicious blending can produce a satisfactory feedstock for cokemaking. The coals used in these blending operations usually have some cokemaking (i.e. thermo plastic) properties. The blending process itself cannot be considered to be innovative although considerable ingenuity is often apparent in the selection of components to provide a continuous plasticity during the heating cycle. Classification procedures are still under development and have produced extensive guidelines for blending. Coupled with experience the guidelines are in continuous reliable use in the steel industry.

Cokemaking blends containing over twelve individual coals have been used in several parts of the world. Canadian practice has rarely been so diverse and current operations require no more than a three component blend.

The major scope for innovation in cokemaking can be inferred from Figure 2. The field of coal characteristics ideal for use in conventional ovens is small and the objective of innovation must be to increase the size of this field by unconventional or modified technology. The "TARGET" thus becomes easier to hit and a wider and cheaper range of coals become candidates for use in the cokemaking process.

## THE CANADIAN CARBONIZATION RESEARCH ASSOCIATION

The methods of applying this basic consideration to the Canadian coal resource provides a major impetus for research activities sponsored by the Canadian Carbonization Research Association.

The Association, formed in 1965, provides an excellent example of industry-government collaboration. The Association membership is drawn dominantly from the Canadian steel and coal industries. The coal resource and processing laboratory in the Department of Energy, Mines and Resources acts as the centre for sponsored bench and pilot-scale research programs.

The Research and Development Program is diverse and uses unique facilities which are located in Ottawa and in Edmonton. At both locations the C.C.R.A. - sponsored activities are lead by scientists who work in collaboration with other coal and energy oriented groups in the Canadian Centre for Mineral and Energy Technology.

A close relationship between research and industrial practice is maintained through the resource evaluation programs conducted on behalf of industry. The technical committee, drawn from the steel and coal industries, meets six times annually and has a general responsibility for the direction of the C.C.R.A.-sponsored research programs. The Board of Directors of the Association is responsible for the overall philosophy of research programs and for budgetary control.

C.C.R.A. SPONSORED RESEARCH

The general purposes of C.C.R.A. sponsored programs are threefold.

1. To provide technical-scale data on Canadian coals and their use in conventional and non-conventional cokemaking. To increase the field of coals used by investigation of such innovations as charge density control by selective pulverization or partial briquetting.
2. To provide novel or improved methods of predicting coke quality from analytical or bench-scale procedures.
3. To provide a reference file of data on Canadian coking coals for use by the steel industry to meet production requirements or by the coal industry to meet customer specifications.

Increases in the size of the field of suitable coals can be achieved by controlled increases in the bulk density of the charge, the most widespread technique in use is selective pulverization. Alternatives such as oiling, mechanical compaction and partial briquetting have all been investigated. Formed coke (which is the subject of another paper in this session) has also been investigated.

The use of charge preheating (to temperatures between 150 and 200$^{o}$C) can also lead to increases in bulk density and a beneficial change in charge porosity due to the reduced moisture content of the charge. Preheating also offers the energy advantages described elsewhere in this report.

Charge density control brings the ever present requirement to keep the expansion of the coal during its plastic deformation within acceptable limits. The pressure on the oven walls must not be allowed to distort or damage the structure no matter what improvement in coke quality might be achieved.

Partial Briquetting

C.C.R.A. sponsored studies of briquetting focus on the interrelationships between briquette concentration, charge bulk density and coke quality when using Canadian coals. Current studies involve the briquetting of three high volatile bituminous coals with one low volatile coal. Three blend ratios are used. The total blend is briquetted and used in a loose blend matrix to produce a partially briquetted charge containing 30% briquettes. The results are assessed by comparison with test data from unbriquetted loose charges from the same parent coals.

The results show that partial briquetting of the selected blends increased both the coke specific gravity and stability.

The program to date has been summarized (3) with the significant conclusion that partial briquetting has its most marked effect when the coke blend was inferior. The technique will therefore have its most useful application in increasing the range of coals capable of producing a high quality coke. Clearly a finely dispersed coal, which would otherwise remain unused in coke making practice, can be used with a binder to produce the briquettes.

Antifissurant Additives

The prime objective of an inert antifissurant additive is to control the excessive plasticity of some high volatile bituminous coals. Fissuring of these coals can result because of gas evolution after solidification of a solid residue or because of extended contraction after the maximum plasticity has occured .

The use of an inert char or coke breeze reduces the contraction which occurs in a bituminous coal both at the onset of plastic deformation and during any secondary contraction during hydrogen or methane evolution at high temperatures. The technology has been well documented in many locations and residual problems for Canadian cokemakers lie chiefly in identification of the optimum additive blend rates to produce the best coke. This type of information has been reliably obtained prior to full scale coke oven trials by experimental programs in the technical scale ovens. These results were subsequently confirmed in plant trials. (4).

It has been clearly established that the inert additive, when used in this way, must be of fine size, preferably below 35 - mesh Tyler screen.(5).

Restoration of Coking Characteristics

It has long been recognized in cokemaking practice that prolonged storage of coking coals leads to oxidation and degradation of the quality of the product. Restoration of the cokemaking characteristic for these coals has been achieved on a laboratory bench scale by blending with a bitumen derived oil from the Great Canadian Oil Sands product stream. Blending of the partially oxidized coal with 5% and 10% oil modified the dilatation and measured plasticity of the coal. An improved coherence of the inert macerels was observed within the coke structure produced in canister tests.

The aromatic aromatic content of the additive is thought to be responsible for an interaction with the residual plastic phases of the oxidized. It appears likely therefore that solvent extracted liquids from coal or coal hydrogenation liquids will have structures comparable to that of the oil used in these experiments and would also prove useful in improving coke quality. It is not yet clear that non-caking coals can be transformed using a technique of this sort. It seems most likely that a degree of thermal plasticity will be required in the coal. This result must be confirmed by technical scale oven trials.

Charge Density Control

The combined effects of coal size distribution bulk density and charge preheating are shown in Figure 3 for a blend of two Canadian coals. The major effect on the product coke was recorded by increasing the bulk density of the charge; the effect is continuous across the entire range of blend ratios.

In the engineering of coke oven operation increases in charge density are largely a consequence of gravity charging or mechanical compaction.

Selective pulverizarion of coal charges is undertaken to ensure that inert components are ground to a finer size than the reactive constituents. The principles which apply are essentially the same as those outlined for antifissurant use.

When good coking coals are available the practice of crushing a blend to 80% below 1/8 inch is adequate. When poor quality coals must be used independent crushing of components to specified sizes prior to blending can result in significant improvements in coke quality.

These activities of C.C.R.A. can, in some ways, be regarded as application and exploration of existing ideas with Canadian coals. It is important to remember that the bituminous coals of Western Canada are unique and have, as yet, only accumulated a small amount of operational experience. The conventional appraisal techniques that have found international use over the past decades are inadequate when applied to Western Canadian coals. A greater reliance than usual has therefore been attached to the technical scale oven research which the Association has developed.

## EMMISSION CONTROL IN COKEMAKING

Canadian cokemaking batteries are located within integrated steel works close to commercial and residential sectors. Historically,environmental concerns have prompted the implementation of emission control technologies. Innovation has focussed on maintenance and operational routines in the older plants. Newer plants have been able to incorporate engineering design changes.

It is this area of emission control, which when coupled with energy conservation that will provide the major technical challenge to the coke oven operators of the future.

### Emissions From Cokemaking Plant

Table 1 lists the major operations responsible for atmospheric emissions from uncontrolled slot type coke ovens. Clearly, the main avenues for control and the best return for investment in control equipment is the charging operation. This contributes at least 40% to each of the emission categories. The other operations are secondary in the quantity of emission discharged and their relative ranking will depend on local interests. For example the sulphur dioxide is an eventual stack emission which is discharged at high level under attractive dispersion conditions. The other gaseous emissions which originate from charging and coking are discharged at a relatively low level. It should be noted that quenching is a major source of particulate emission.

## Emission Control Technology

Control technologies for each of the problem areas in the cokemaking process are under continuous review and development. In some instances the review has led to innovation and in others to improved housekeeping.

### Coal and Coke Handling

Three main techniques are employed in coal handling. Dust suppression by wetting, complete enclosure of handling facilities and improved extraction and air cleaning systems incorporating closed conveyors.

Similar techniques can be applied to cold coke handling. Emission control by wetting however poses an immediate problem in that it can reduce the fuel economy in the blast furnace.

### Oven Charging

These major emissions are chiefly the early products of coal pyrolysis liberated when the fresh charge comes in contact with the hot oven walls. The particulate material at this time is chiefly soot (polymerized carbon) and the hydrocarbons are condensed tars with some low carbon gases. Carbon monoxide and nitric oxide reflect the availability-albeit limited of oxygen.

The general technologies that have been developed fall into three categories:

1. Collection of emission gases in collecting mains by oven draft control and
2. external collection and cleaning of the gases by the larry car or in stand pipes and
3. sealed charging of coal which may be preheated.

The third of these alternatives will offer the advantage of increased oven productivity.

Staged charging is essentially an operational solution which has been applied in many ovens. The charging locations are maintained under vacuum and the oven is cross ventilated towards the extraction collecting main. The initial pyrolysis products condense in the collecting mains which increased the maintenance schedules. The control is practical and is easily implemented in relatively airtight ovens. Where the ventilation flow can be supported by aspiration driven by steam or water jets in the stand pipes, little or no modification is required to be made to the ovens.

External collection of waste gases during charging is based on a complex larry car design which has the function of charging the oven through one charging port and cleaning the effluent gas from other unused charging ports. The car is equipped with extract fan system. The effluent gases can be either incinerated and wet scrubbed or wet scrubbed alone. In both instances venturi scrubbers are used to reduce the pariculate emission by up to 90%. However the use of combustion followed by wet scrubbing can lead to an increase in nitric oxide emission due to the combustion process.

A typical installation is illustrated schematically in Figure 4.

These two mechanisms of emission control during charging do not affect the coke oven performance. If however a sealed charging system can handle pre-heated coal then we start to see major benefits in both emission control and oven efficiency.

Two alternative methods of preheated coal charging, which are illustrated in Figure 5, involve pneumatic transport of the preheated coal to the oven. The charging system is therefore totally sealed during entry.

There is, implicit in the preheating process, a reduction in the heat requirement at the oven of a magnitude which is dependent on the moisture content of the coal. It is important to note that, in addition to the energy saving there is a time saving in the oven essentially equivalent to the drying and evaporation stages of the coking cycle. This gives rise to an increase in oven throughput which can be as much as 50% together with a reduction in breeze quantity. This could lead to decreased battery size for a given throughput; the capital and operating cost will not necessarily reduce in the same proportion.

Research into the effects of preheat on coke quality has indicated that a significant improvement in coke quality can be achieved particularly where usual practice is gravity charging. It appears also that pore structure and consistency are improved. This is clearly of major significance as strength requirements increase with increasing blast furnace size. It is also suggested that preheating can eliminate the need to keep the oven charge level. The use of preheat in the Gary coking plant of U.S.steel in conjunction with a blast furnace trial has shown an overall improvement in blast furnace output and generally smoother operation.

Oven Pushing

Completely coked coal is the best guarantee of minimum emissions during pushing. Green coke - which contains large residual quantities of polymerized volatile components - gives rise to massive soot emissions on exposure to the atmosphere. Control of these emissions is largely achieved by shrouding the exit route of the coke in a mechanically ventilated hood. Figures 6 & 7. This hood forms part of quench car and seals onto each oven door-frame during the push.

The exhaust gases - which are a mixture of air and coke combustion products containing soot and particulate materials - can be either cleaned with a scrubber system on the quench car or circulated in a central main to a ground gas cleaning facility.

Heat Recovery in Coke Quenching

Figure 8 shows that the overall energy balance of the coke oven battery can be massively improved if the heat loss during wet quenching can be recovered. This loss amounts to approximately one half of the gaseous energy input.

It is also clear that dry cooling and preheating can be combined to produce a more energy efficient coke oven operation without whilst simultaneously producing an improvement in coke quality. (6).

The principle of dry cooling is direct recovery of the sensible heat of the product coke using an inert gas as the heat transfer medium in a closed circuit system. The inert gas takes up heat from the coke and transfers the heat to a waste heat boiler where steam is generated. The cooled gas is recirculated to the hot coke.

Coke quenching using this technique reduces coke temperatures and leads to a major heat recovery. Overall this corresponds to about 3% of the total energy consumption in steel-making. The consequent change (improvement) in blast furnace operation due to the use of a dry coke feed has been measured as a reduction in coke consumption of 1% per ton of hot metal. This benefit, when added to the value the steam produced in the waste heat boiler, indicates that the pay off for a dry cooling plant would be less than four years.

The waste heat recovery as steam is not necessarily simple since the recovery must be made on a cyclic basis to match the individual ovens in the battery. The techniques of steam accumulation and supplementary firing will necessarily be used in the steam system. A recent design incorporates cold gas blending with the hot inert gas to control the steam output from the boiler. As the coke cools an automatic reduction in dilution gas flow maintains heat transfer characteristics of the waste heat boiler.

## CLOSURE

The continued role of the blast furnace as the central component in the steel industry guarantees cokemaking technology a future. In that future the cokemaking industry must provide answers to problems that are created by international shortages of prime coking coals and increasingly stringent environmental control. The solutions that are achieved must be achieved within the constraint of decreasing coke use per ton of hot metal.

The co-operative effort that has been undertaken within the framework of the Canadian Carbonization Research Association will continue to play a major role in responding to these problems as they affect Canadian industry.

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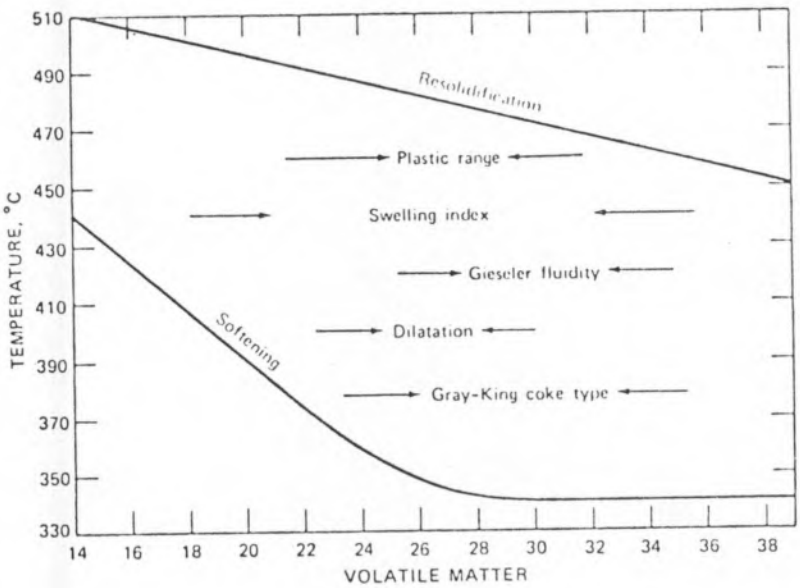



Fig. 1 Variation in the Plastic Properties of Coal with Volatile Matter

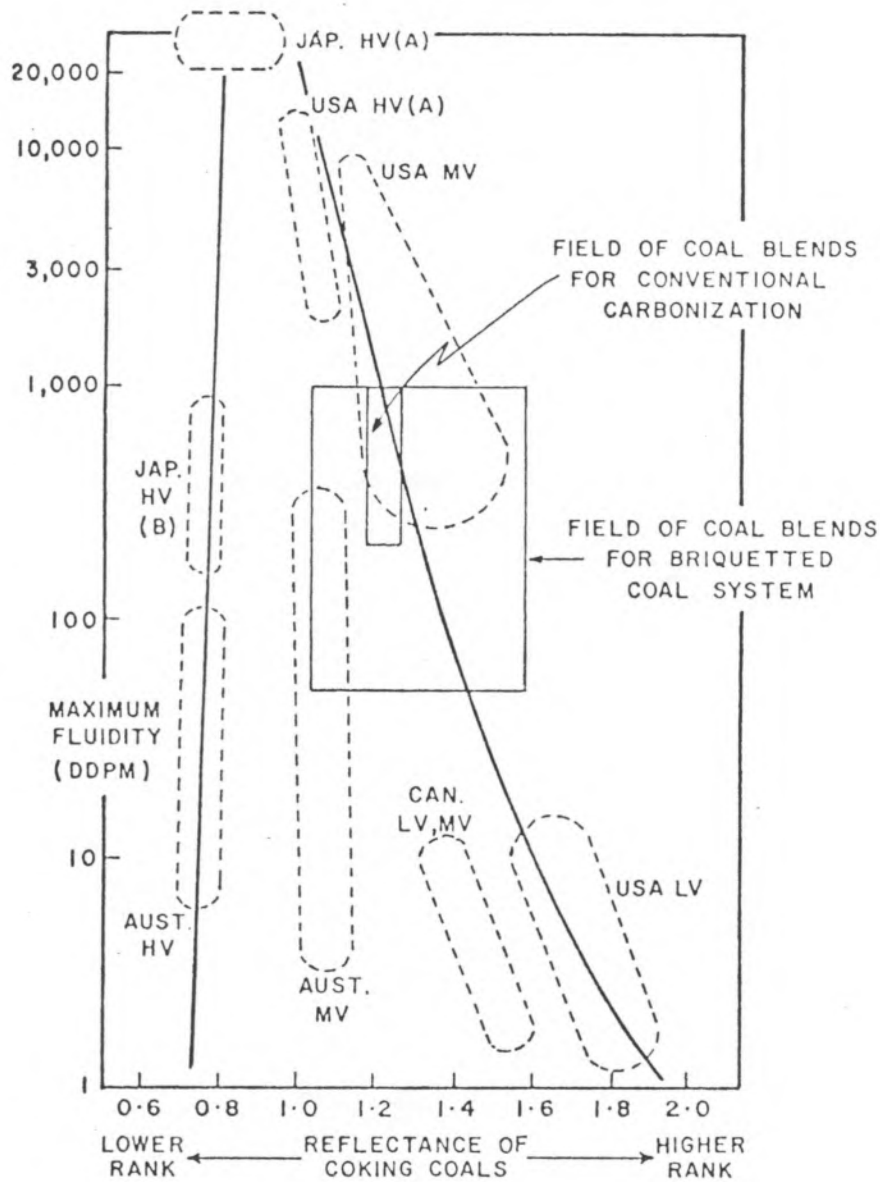



Fig. 2 Fluidity of Bituminous Coals vs Rank Showing Acceptable Range of Coking Coal Properties for Conventional and 30 Per Cent Partially Briquetted Charges (after NKK Technical Paper, reference 33).

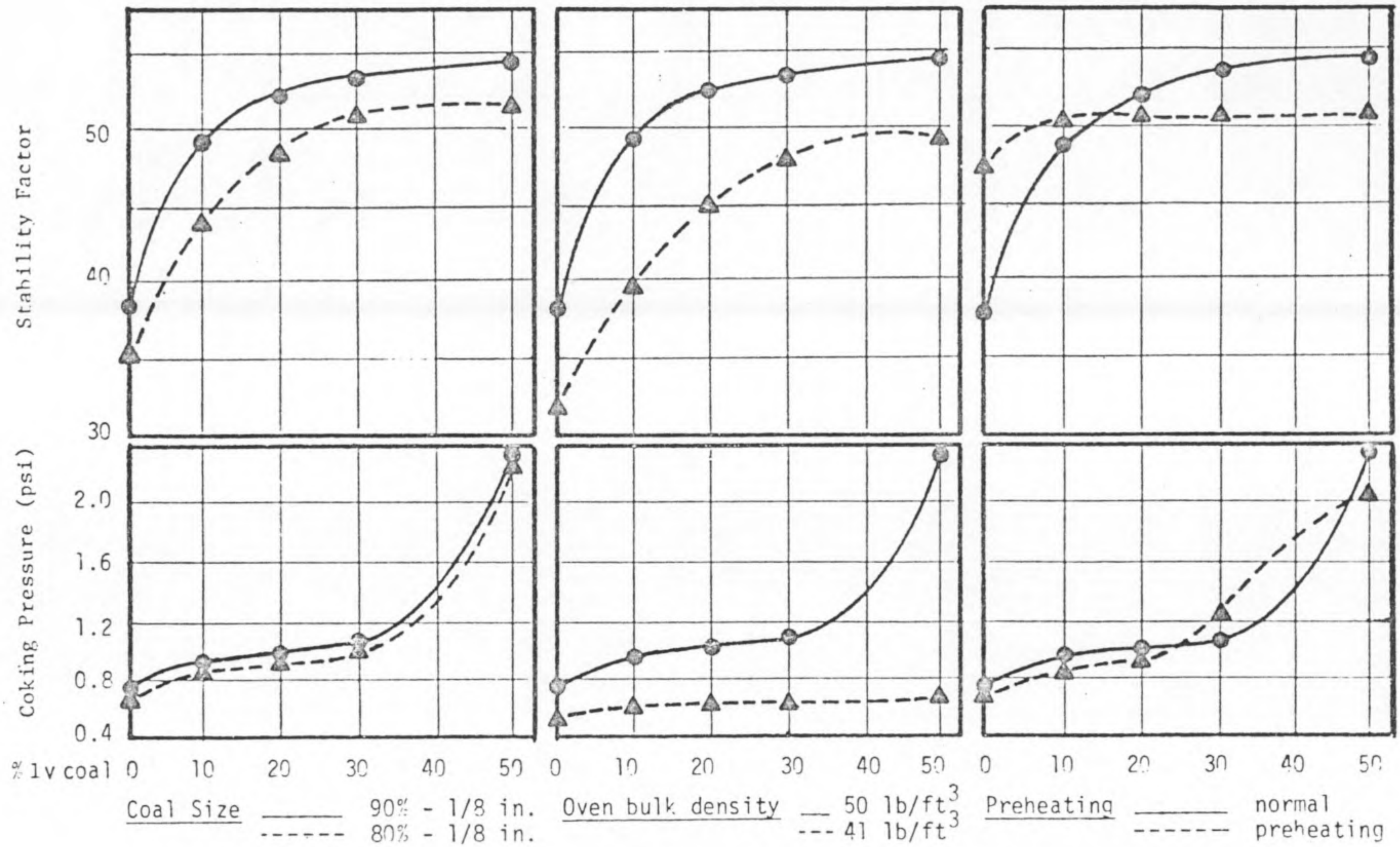



Fig. 3 The effect of coal particle size, oven bulk density and coal preheating on coke strength (Stability Factor) and coking pressure with varying proportions of lv coal blended with a hv coal (Unreported CANMET results).

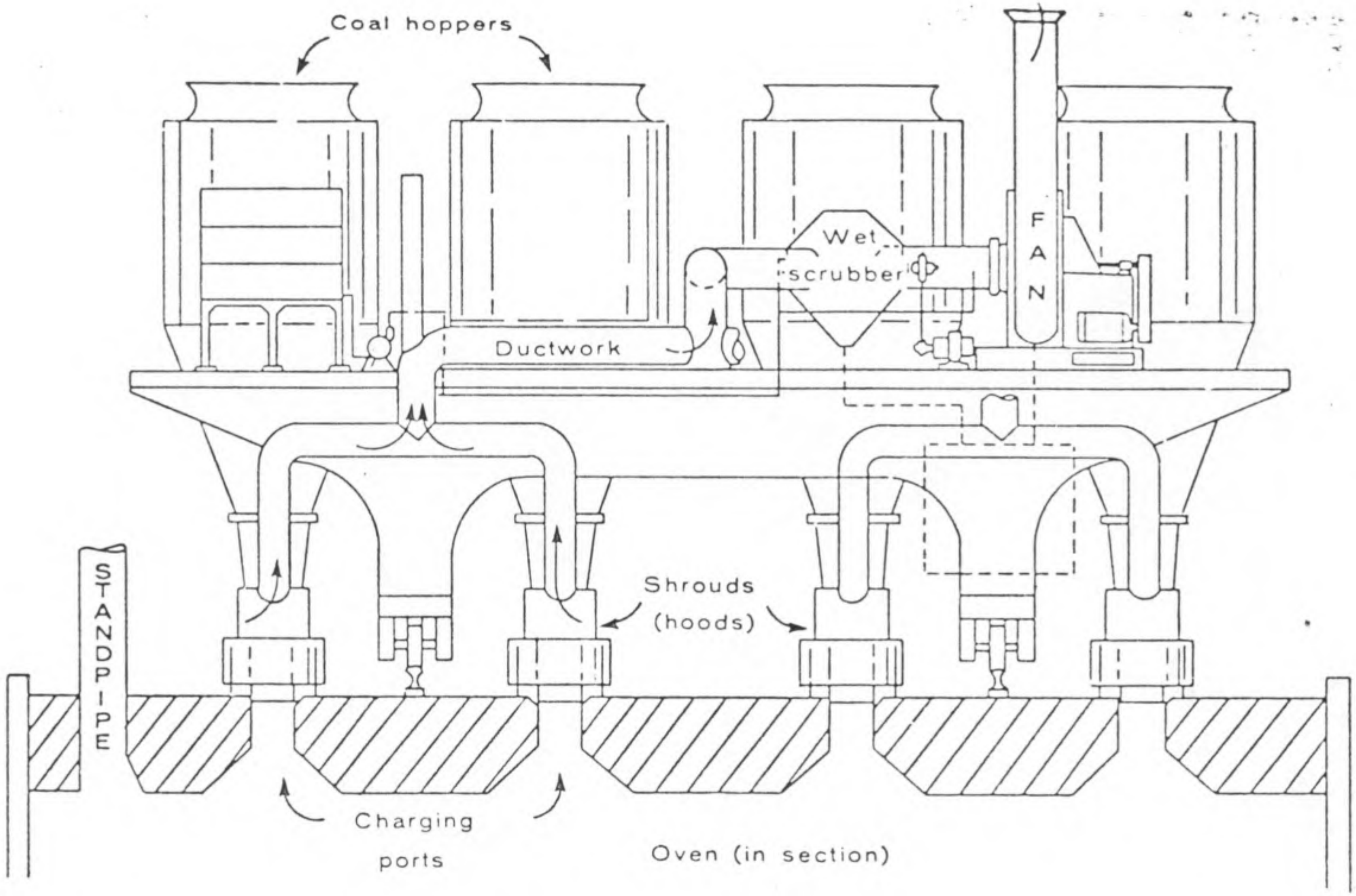
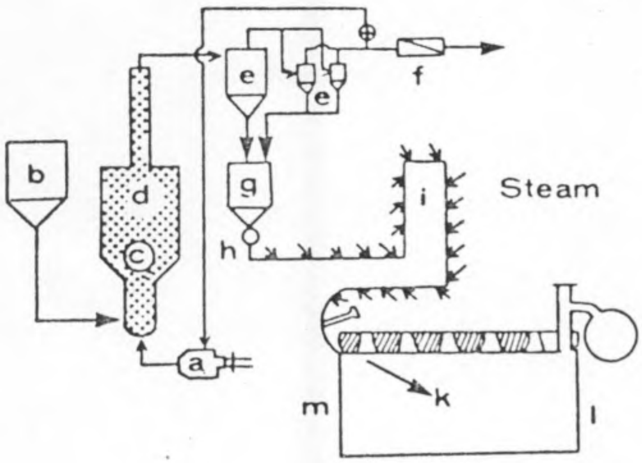



Fig. 4 Representative Larry-Car-Mounted Wet-Scrubbing System

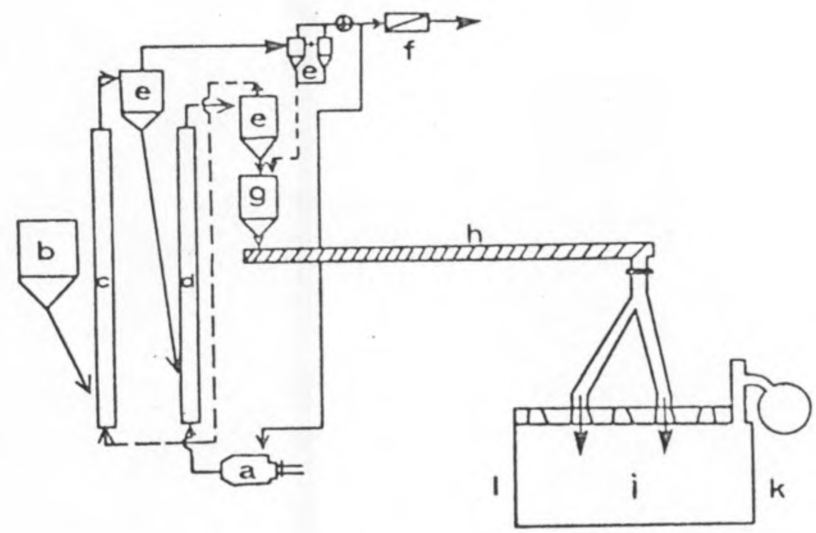



Coaltek process:

c-Hammermill
d-CERCHAR dryer
h-Coal valve
i-Pneumatic ducting

Common symbols:

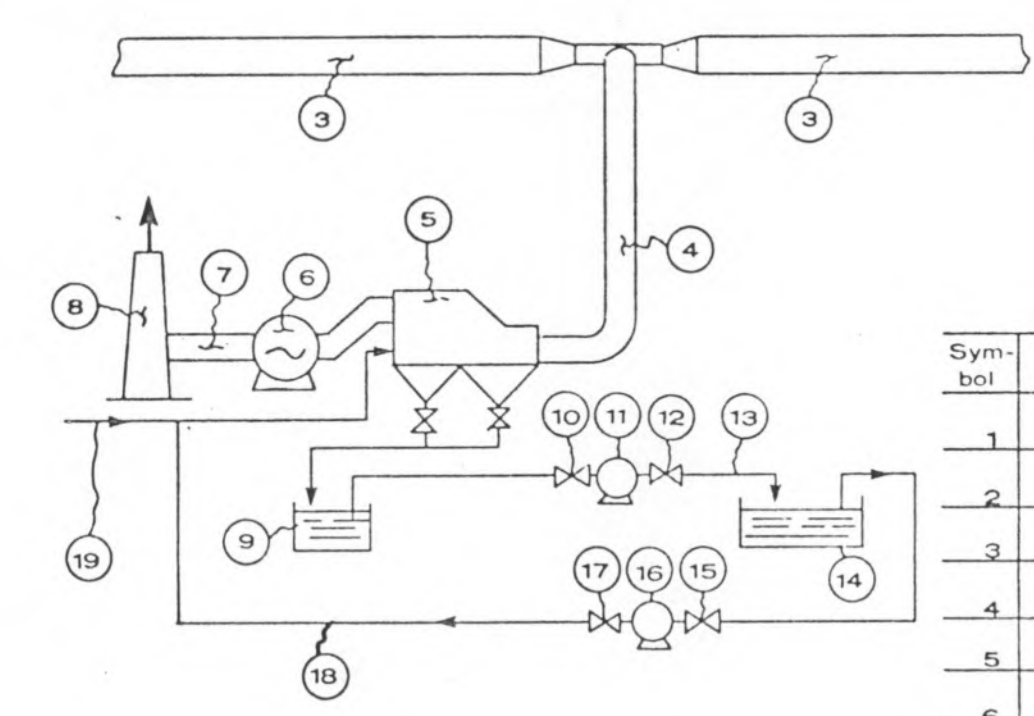
a-Combustion chamber
b-Input bunker
e-Cyclone
f-Wet scrubber
g-Measuring bunker
i,k-Coke oven
j,l-Coke side
l,m-Machine side




Precarbon process:

c-Drying column
d-Heating column
h-Redler conveyor

Figure **5** Coaltek Pipeline Charging and Precarbon Redler Charging of Preheated Coals Through Sealed Systems



| Symbol | Name |
|---|---|
| 1 | Hood |
| 2 | Connector |
| 3 | Oven front duct |
| 4 | Connecting duct |
| 5 | Dust collector |
| 6 | Suction fan |
| 7 | Damper for adjustment of air flow |
| 8 | Stack |
| 9 | Drain pit |
| 10 | Drain pump inlet valve |
| 11 | Drain pump |
| 12 | Drain pump outlet valve |
| 13 | Drain pipe |
| 14 | Extinguish & cooling setting basin |
| 15 | Feed water pump inlet valve |
| 16 | Feed water pump |
| 17 | Feed water pump outlet valve |
| 18 | Feed water pipe |
| 19 | Water supply |

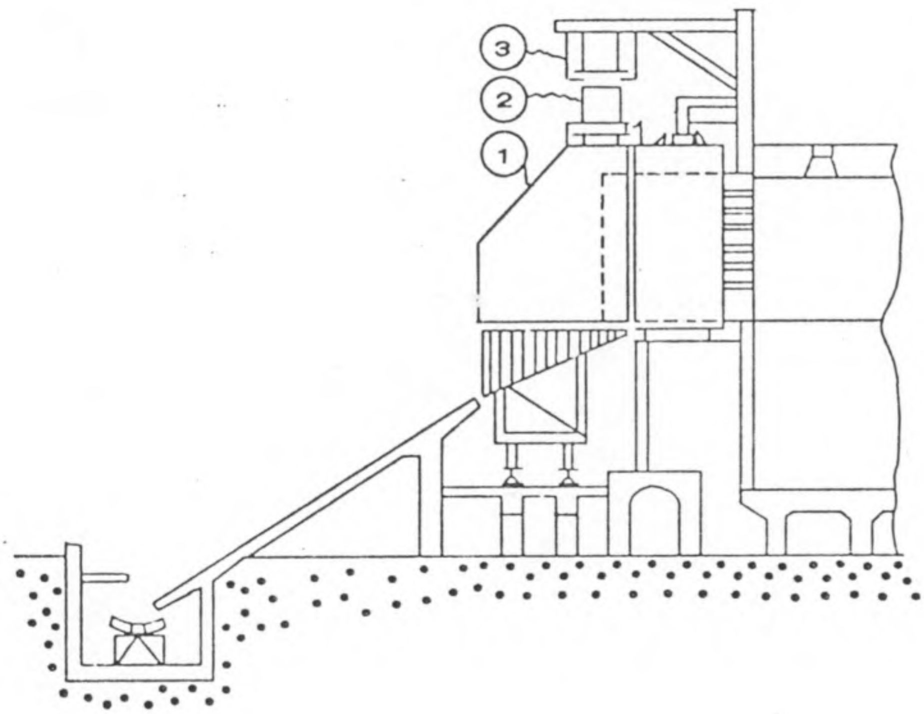


Fig. 6 Mitsubishi-Amagasaki-Shinwa Smokeless Pushing Technology

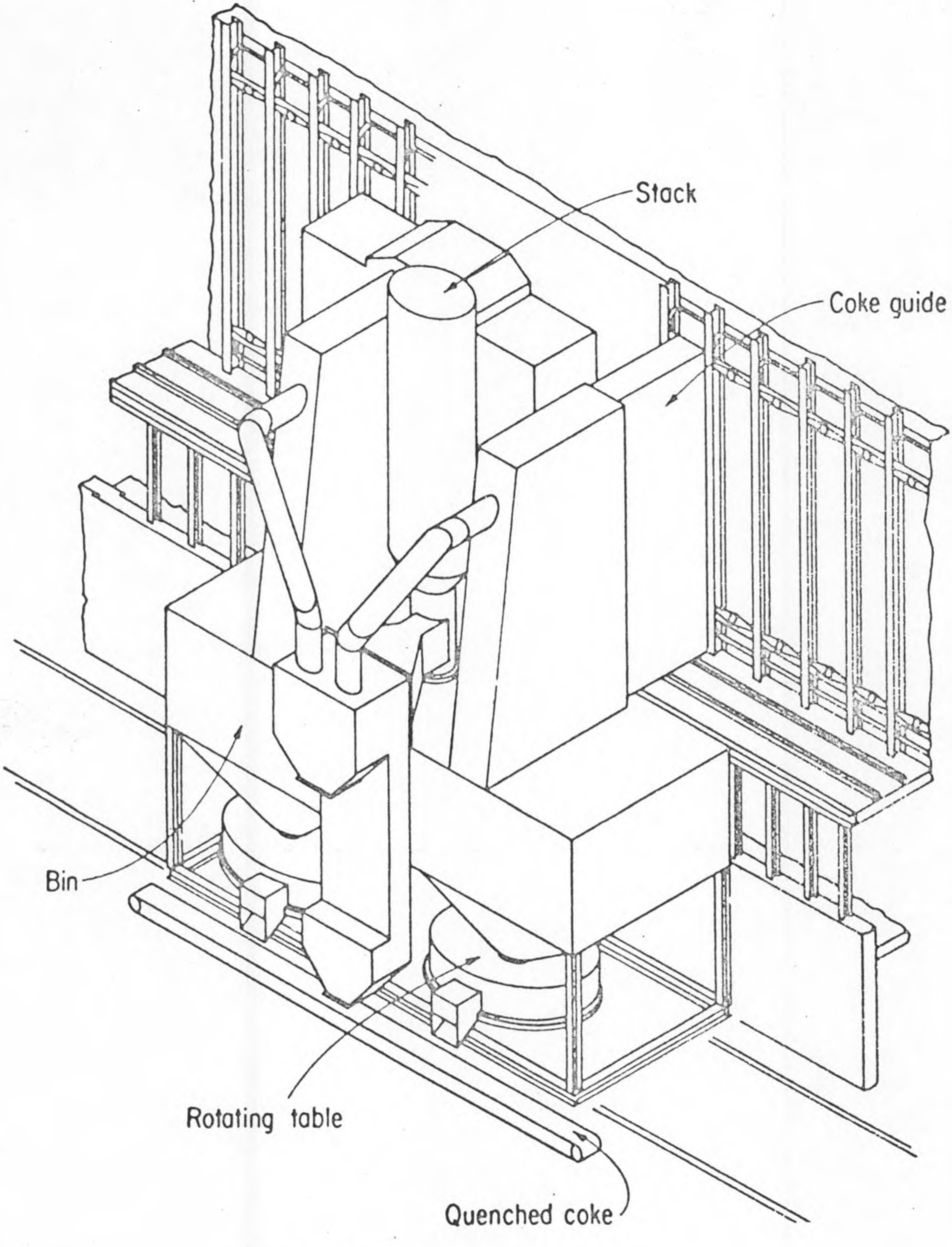



Fig. 7 Mobile - Type Rotary Quencher

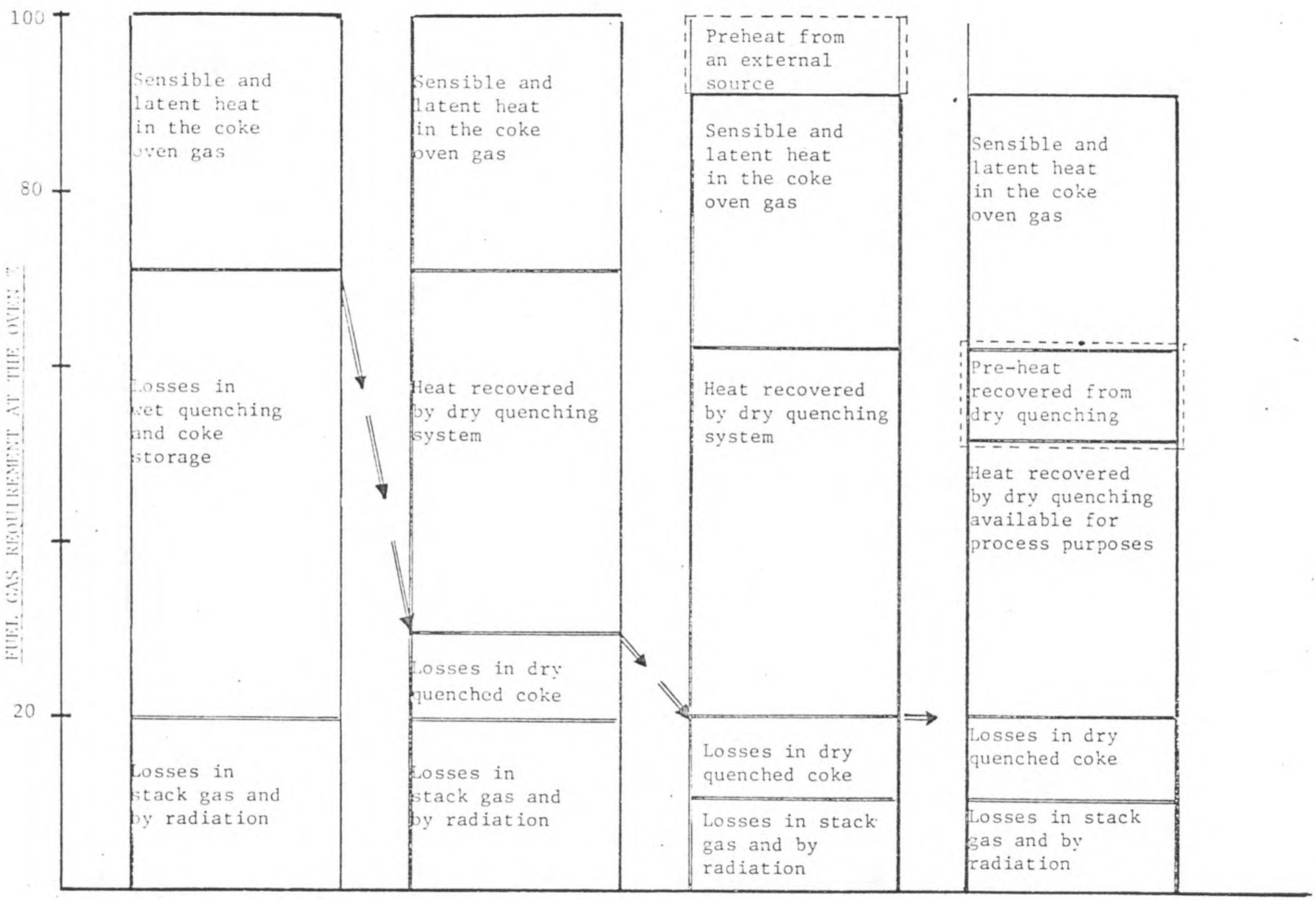



FIGURE 8: FUEL GAS REQUIREMENTS IN COKEMAKING

(AFTER BARKER, REFERENCE 5)

TABLE 1

REPRESENTATIVE EMISSION FACTORS FOR UNCONTROLLED

METALLURGICAL COKE MANUFACTURING OPERATIONS

(Taken from "Compilation of Air Pollutant Emission Factors
Second Edition, U.S.Environmental Protection Agency)

EMISSION IN LB/TON OF COAL CHARGED

| COKE OVEN OPERATION | PARTICULATES | SULPHUR DIOXIDE | CARBON MONOXIDE | HYDRO- CARBONS | NITROGEN OXIDES | AMMONIA |
|---|---|---|---|---|---|---|
| Charging | 1.5 | 0.02 | 0.6 | 2.5 | 0.03 | 0.02 |
| Coking | 0.1 | | 0.6 | 1.5 | 0.07 | 0.06 |
| Discharging | 0.6 | | 0.07 | 0.2 | | 0.1 |
| Quenching | 0.9 | | | | | |
| Underfiring | - - | 4 | | | | |
| TOTAL | 3.1 | 4.02 | 1.27 | 4.2 | 0.04 | 0.18 |