SECOND EDITION

Boiler Operation Engineering

Questions and Answers

P. Chattopadhyay

Boiler Operation Engineering

Questions and Answers

Second Edition

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Preface to the Second Edition

Thanks to the reviewer nominated by the editorial board of the POWER magazine (McGraw-Hill, Inc., NY 10011, USA) for reviewing the first edition of the book: *Boiler Operation Engineering: Questions and Answers*. Based on his valuable suggestions, I have incorporated a number of 'addendums' in this second edition of the book and the obsolete portions have been deleted.

The book has been expanded to accommodate six more chapters:

- **Upgrading PC-Fired Boilers**
- **Low NO_x Burners**
- **Emissions Control**
- **Cooling Water Treatment and Cooling Towers**
- **Reverse Osmosis**
- **NDE and Condition Monitoring**

There have been addendums to almost all chapters. The important ones are latest plant operation data, illustrations and photographs on Fluidized Bed Boilers, Fluidized Bed Boiler Design, Steam Turbines, Water Treatment and Demineralization, Ion-Exchange Resins, Cooling Tower Designs, LNBs, CASE STUDIES and many others.

Many new topics added in the APPENDIX such as Zero Liquid Discharge, NDT of Rotating Equipment, BFW Pump Availability, Boiler Refractories and their Installation, Control Valves and their Sizing, Steam Traps, Reverse Osmosis, Ion Exchange Resins Handling, Filling, Operation and Maintenance, Protection, and many others have expanded the scope of the relevant topics discussed in the mainframe text.

This edition will be very helpful to engineers and operator directly in charge of boilers, candidates appearing for first and second class Boiler Certificate Examination and Boiler Operation Engineering examinations, power plant personnel and students of power plant engineering.

Assistance, in any form from any corner, for the improvement of the book is most cordially welcome and will duly be appreciated.

P Chattopadhyay

Preface to the First Edition

The production of steam and its utilization have undergone a radical change over the years as an outcome of the pioneering efforts of scientists and engineers in the field of fuel and combustion technology, boiler operation, and power generation.

Though there are many excellent texts dealing separately with these subjects, engineers and operators in charge of boiler operation may find it difficult to obtain a single book covering the various aspects of boiler operation technology. I hope this book will fulfil their requirements and also be advantageous to students undergoing courses in power plant engineering and fuel combustion technology.

The book is based on four interrelated disciplines in the production and utilization of steam:

- Water treatment and water conditioning
- Combustion of fuels and the physico-chemical principles involved
- Boilers and steam generation
- Utilization of steam for power generation

The subject matter is presented in a question-answer form. Real-life problems have been supplemented with study matter pertaining to the basic concepts, and numerical calculations, wherever necessary, have been incorporated for better understanding of the subject.

However, with the growing concept of efficient combustion of fuel, utilization of low calorie fuels, and better pollution control measures, the methods of production and utilization of steam are becoming more and more complex: the old ones phasing out to give way to the new. Therefore, in a sense the book is incomplete. And I will be grateful to those who will lend it completeness by giving constructive criticism and suggestions for further improvement of the book.

I sincerely acknowledge my indebtedness to Mr Debu Roy, my friend and colleague for checking the numerical calculations in the manuscript. I am grateful to my wife, Honey, for ferreting out a good many typographical mistakes and omissions from the typescript.

P Chattopadhyay

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Contents

Nomenclature

AFS	Axial Flame Staged
AMP	Aminomethylene Phosphonate
Anex	Anion Exchange
AOFA	Advanced Over Fire Air
AS	Ammonium Sulphate
ASR	Axial Staged Return flow
ATM	Atmosphere
AVT	All Volatile Treatment
BBF	Biased Burner Firing
BCDMH	1-Bromo-3-Chloro-5, 5-dimethylhydantoin
BD	Blowdown
BFW	Boiler Feed Water
BOD	Biological Oxygen Demand
BOOS	Burner Out of Service
BPE	Boiling Point Elevation
BW	Boiler Water
BWR	Boiling Water Reactor
CA	Cellulose Acetate
CAA	Clean Air Act
CAAA	Clean Air Act Ammendments (of 1990)
Catex	Cation Exchange
CBD	Continuous Blow Down
CCR	Countercurrent Regeneration
CCSEM	Computer Controlled Scanning Electron Microscopy
CDI	Continuous Deionization
CF	Controlled Flow
CFR	Coflow Regeneration
CETF	Combustion & Environment Test Facility
CHF	Critical Heat Flux
COD	Chemical Oxygen Demand
c/o	Carryover
C/Over	Carryover
CS	Carbon Steel
CT	Cooling Tower
C/T	Cooling Tower
C/W	Cooling Water
CTA	Cellulose Triacetate
CTBD	Cooling Tower Blowdown
CVCS	Chemical & Volume Control System
DAF	Distributed Air Flow
DBMPA	Dibromo-nitrilo-propionamide
DEP	Department of Environmental Protection
DMH	Dimethylhydantoin
DMP	Demineralization Plant
DO	Dissolved Oxygen
DPT	Dew Point Temperature
EBD	Emergency Blowdown
E/C	Erosion / Corrosion
EDR	Electrodialysis Reversal
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FAC	Free Available Chlorine
FC	Fixed Carbon
FD	Flash Drum
FGD	Flue Gas Desulfurization
FGR	Flue Gas Recirculation
FMA	Free Mineral Acidity
FW	Feed Water
FWEC	Foster Wheeler Energy Corporation
GRT	Gamma Ray Tomography
GT	Gas Turbine
HE	Heat Exchanger

HEDP	Hydroxy-ethylidine-diphosphonate
HPPAH	Heat Pipe Primary Air Heater
HRSG	Heat Recovery Steam Generator
ICGCC	Integrated Coal Gasification Combined Cycle
IEx	Ion Exchange
IFS	Internal Fuel Staged
i/l	in line
IRZ	Internal Recirculation Zone
ISSS	Integral Separator Startup System
LEA	Low Excess Air
LNB	Low NO_x Burner
LNO_x	Low NO_x
LRCA	Level Regulator Control & Alarm
L/up	Lined up
LWR	Light Water Reactor
MEH	Methylhydantoin
MOC	Materials of Construction
MSW	Municipal Solid Waste
ND	Natural Draft
NDE	Non-Destructive Examination
NDT	Non-Destructive Testing
Op	Operating
OEM	Original Equipment Manufacturer
OFA	Overfire Air
O & M	Operation & Maintenance
OSC	Off-Stoichiometric Combustion
OSHA	Occupational Safety & Health Act
OTU	Once Thru Unit
PA	Primary Air; Pulverizer Air
PAH	Primary Air Heater
PB/RF	Packed Bed / Reverse Flow
PBTC	Phosphono-Butane-Tricarboxylate
PC	Pulverized Coal
press.	Pressure
PSI	Practical (or Puckorius) Scaling Index
qty	Quantity
RAPH	Reduced Air Preheat
RF	Reverse Flow
RO	Reverse Osmosis
RO/MB	Reverse Osmosis & Mixed Bed in tandem
SAC	Strong Acid Cation Exchange Resin
SAS	Secondary Air Staging
SBA	Strong Base Anion Exchange Resin
SDI	Silt Density Index
s/d	Shutdown
SEMPC	Scanning Electron Mircoscopy Point Count
SF	Split Flame
SGP	Steam Generation Plant
SH	Superheated
SHMP	Sodium Hexa Meta Phosphate
SNCR	Selective Non-Catalytic Reduction
S-OFA	Standard Over Fire Air
SRV	Safety Relief Value
SS	Stainless Steel
ST	Steam Turbine
STS	Swirl Tertiary Staged
SV	Safety Value
TA	Turboalternator
TCS	Temperature Coefficient of Solubility
TD	Turndown
TDS	Total Dissolved Solids
temp.	Temperature
TG	Turbogenerator
THM	Trihalomethane
TLN	Tangential fired Low NO_x
TMA	Theoretical Mineral Acidity
TOC	Total Organic Carbon
TPS	Thermal Power Station
TSP	Trisodium Phosphate
TSS	Total Suspended Solids
UPS	Uniform Particle Size
VCE	Vapor Compression Evaporator
VM	Volatile Matter
VR	Velocity Recovery
WAC	Weak Acid Cation Exchange Resin
WBA	Weak Base Anion Exchange Resin
WSI	Water / Steam Injections
XAFS	X-ray Absorption & Fine Structure
ZLD	Zero Liquid Discharge

1

BOILERS

Q. *What is a boiler?*

Ans. Broadly speaking, a boiler is a device used for generating, (a) **steam** for power generation, process use or heating purposes, and (b) **hot water** for heating purposes.

However, according to the Indian Boiler Act, 1923, a boiler is a closed pressure vessel with capacity exceeding 22.75 litres used for generating steam under pressure. It includes all the mountings fitted to such vessels which remain wholly or partly under pressure when steam is shut-off.

Q. *What is the difference between a steam boiler and a steam generator?*

Ans. Technically speaking, a steam boiler consists of the containing vessel and convection heating surfaces only, whereas a steam generator covers the whole unit, encompassing waterwall tubes, superheaters, air heaters and economizers.

Q. *How are boilers classified?*

Ans. Boilers are classified on the basis of:

1. Mode of circulation of working fluid
2. Type of fuel
3. Mode of firing
4. Nature of heat source
5. Nature of working fluid
6. Position of the furnace
7. Type of furnace
8. Boiler size
9. Materials of construction
10. Shape of tubes and their spatial position
11. Content of the tubes
12. Steam pressure
13. Specific purpose of utilization
14. General shape
15. Manufacturer's trade name
16. Special features.

Q. *What is circulation?*

Ans. It is the motion of the working fluid in the evaporating tubes. This motion is effected by head or pressure difference in the working fluid between the downcomer and uptake (riser) tubes.

The circulation may be natural or forced and the circulation circuit formed by the heated and unheated tubes may be a closed or open hydraulic system.

In natural (Fig. 1.1) and forced multiple circulation boilers (Fig. 1.2), the circulation circuit is a closed hydraulic system. While a once-through boiler represents an open-hydraulic system (Fig. 1.3). In combined-circulation (Fig. 1.4) boilers, the plant operates on closed hydraulic system at the start-up and is switched over to an open hydraulic system after attaining the specified load.

Q. *How are boilers classified on the basis of mode of circulation of working fluid?*

Ans. On the basis of mode of circulation of working fluid, boilers are classified into

1. Natural circulation boiler
2. Forced (i.e. positive) circulation boiler

Q. *What is natural circulation?*

Ans. The natural convection of water set up in the closed hydraulic system of heated and unheated tubes of the waterwall.

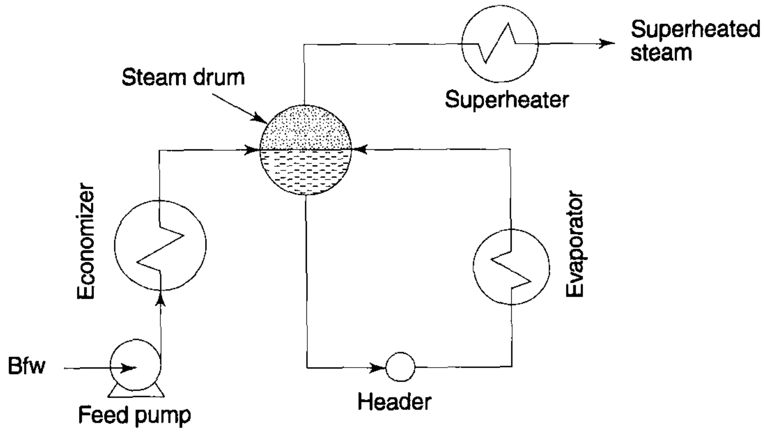

Fig. 1.1 *Natural circulation. It is a closed circuit in which the working fluid circulates by virtue of its density difference*

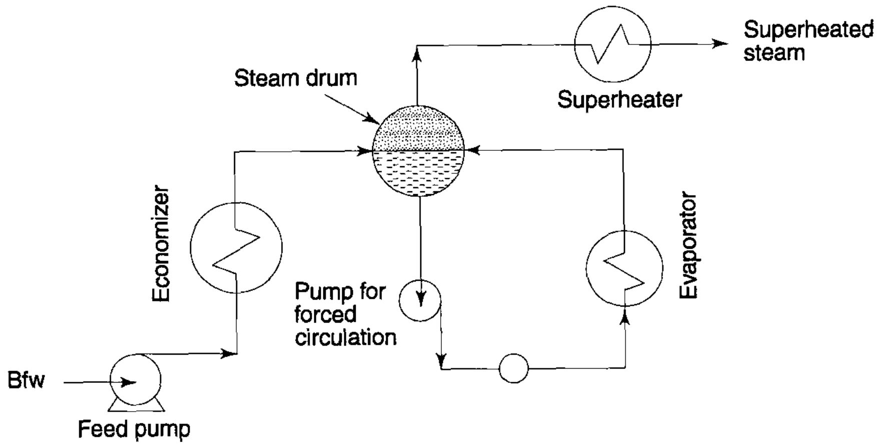

Fig. 1.2 *Multiple forced circulation. It is a closed hydraulic system in which the working fluid is circulated by forced circulation pump*

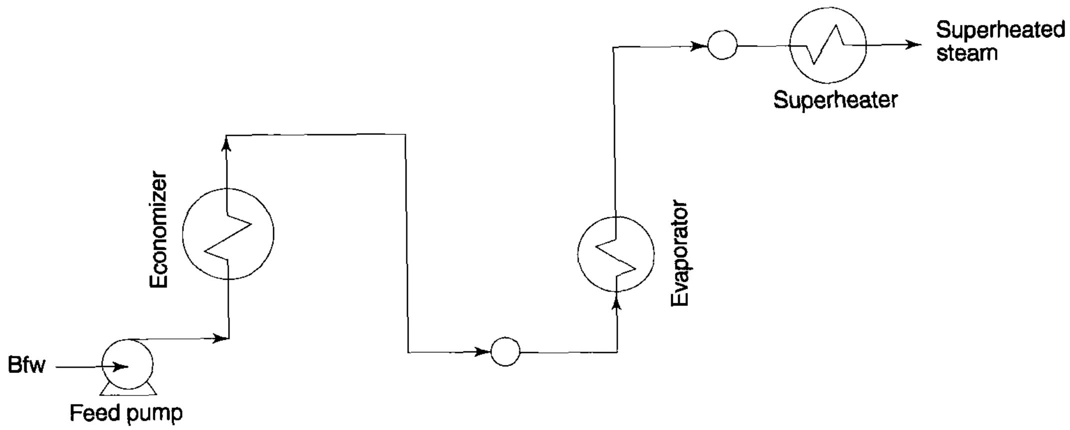

Fig. 1.3 *Open-hydraulic circuit. This system is adopted for once-through boilers*

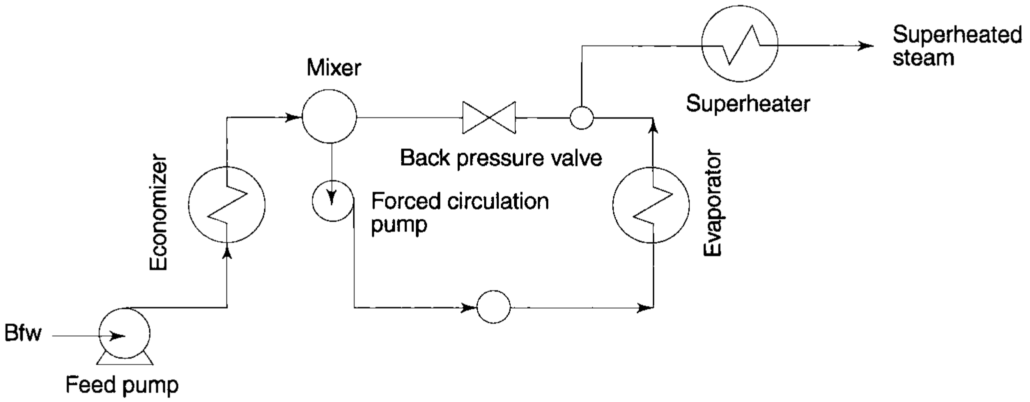

Fig. 1.4 *Combined circulation. It operates on closed hydraulic system at low load and open hydraulic systems beyond specified load*

Q. *How is natural circulation accomplished?*

Ans. The natural convection current is induced to water due to a difference in density resulting from difference in temperature.

The baffle separates out the heated riser from the unheated downcomer and therefore creates a temperature difference between the two tube systems.

Saturated water flows down the unheated downcomer and receives heat in the riser whereupon a part of it gets converted into steam. The difference in densities of saturated water in the downcomer and the steam-water mixer in the riser brings about natural circulation. (Fig. 1.5)

Q. *What is the limitation of natural circulation?*

Ans. It is applicable to all subcritical boilers, i.e. all those which are operating at a pressure less than critical pressure.

Q. *What is forced circulation?*

Ans. If the working fluid is forced through the boiler circuits by an external pump, the ensuing circulation is called positive or forced circulation.

Q. *What are the advantages of forced circulation over natural circulation?*

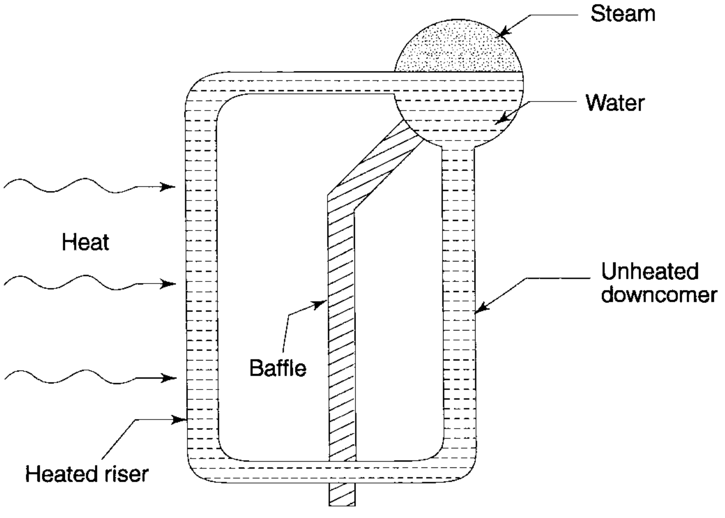

Fig. 1.5 *Natural circulation mechanism*

Ans.

1. Steam generation rate is higher
2. Greater capacity to meet load variation
3. Quicker start-up quality from cold
4. Lower scaling problem due to high circulation velocity
5. More uniform heating of all parts reduces the danger of overheating and thermal stresses
6. Smaller tube diameter and hence lighter tubes
7. Greater freedom in arrangement of furnace, boiler component and tube layout
8. Operating temperature and pressure can be made to deviate from the designed values.

Q. *What is circulation ratio?*

Ans. It is the ratio of the mass flow rate of circulating water (G_{fw} t/h) to the rate of steam generation (G_s t/h)

$$k = G_{fw}/G_s$$

Q. *What is the value of circulation ratio for natural circulation?*

Ans. It usually ranges from 4 to 30.

Q. *What is the value of circulation ratio for forced circulation?*

Ans. It ranges from 3 to 10.

Q. *What is the value of circulation ratio for once-through steam boilers?*

Ans. Unity.

Q. *Why is the value of circulation ratio for once-through boilers unity?*

Ans. In such units, (Figs 1.6 and 1.7) the entire feed-water is continuously converted to steam as it passes through the evaporating surfaces, i.e.

$$G_{fw} = G_s$$

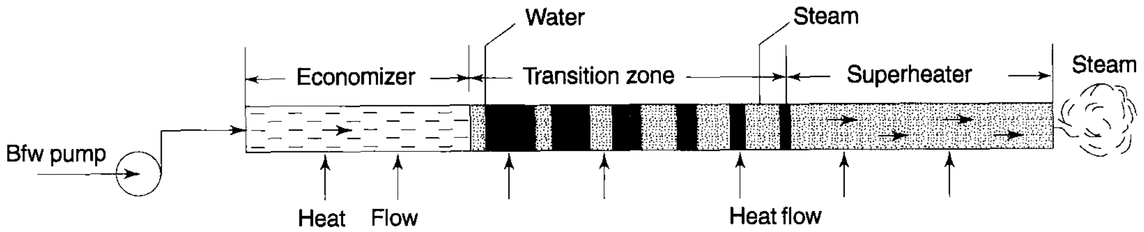

Fig. 1.6 *Transformation of BFW to steam in once-through boiler*

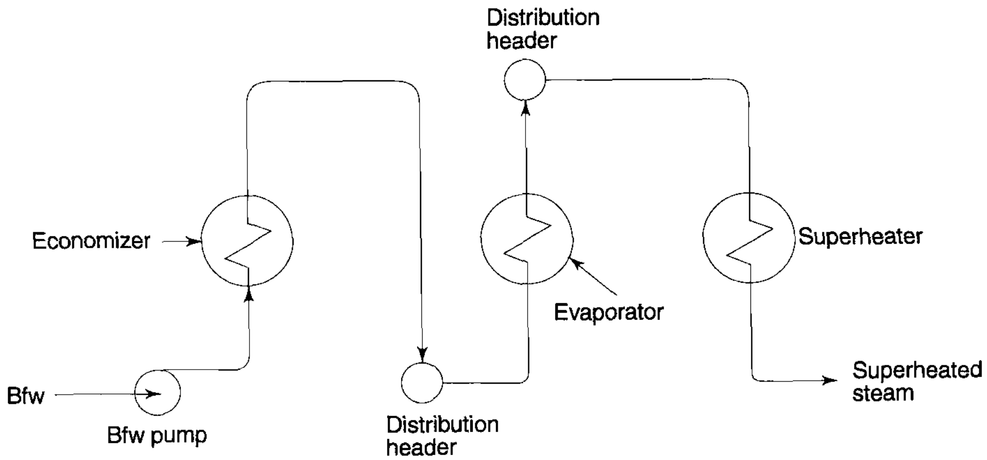

Fig. 1.7 *Once-through circuit*

Q. *Can once-through boilers operate at subcritical as well as supercritical pressures?*

Ans. Yes.

Q. *What is the difference between a closed hydraulic system and an open hydraulic system?*

Ans. The former features a drum that acts both as a reservoir to provide working fluid circulation and separator to separate water from steam, while the latter has no drum and the working fluid passes through the evaporating tubes only once.

Q. *How can boilers be classified on the basis of tube shape and position?*

Ans. Depending on the form of tubular heating surface, boilers may be classified as

1. Straight tube boilers
2. Bent tube boilers.

Depending on the inclination of tubular heating surface, boilers may be classified as

1. Horizontal Boilers (Fig. 1.9)
2. Vertical Boilers (Fig. 1.8)
3. Inclined Boilers.

Q. *What is the difference between a horizontal boiler and a vertical boiler?*

Ans. The difference basically lies in the geometric position of the boilers.

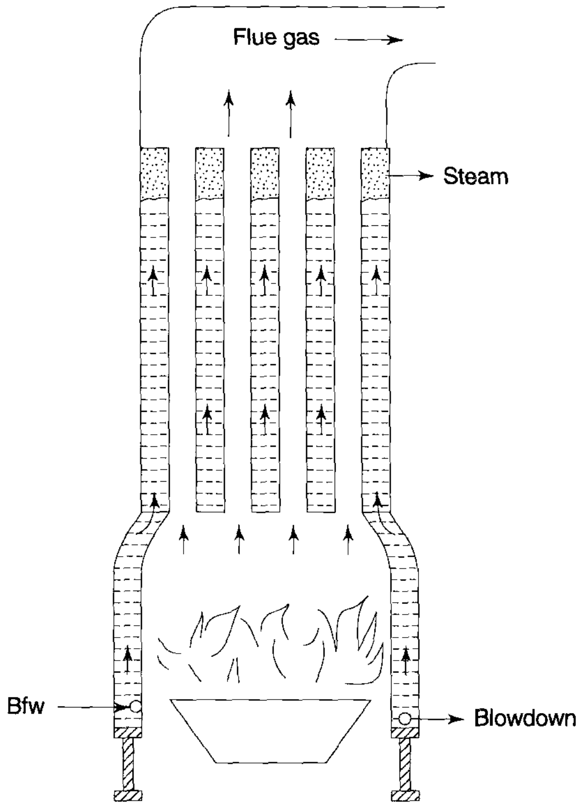

Fig. 1.8 *Vertical boiler*

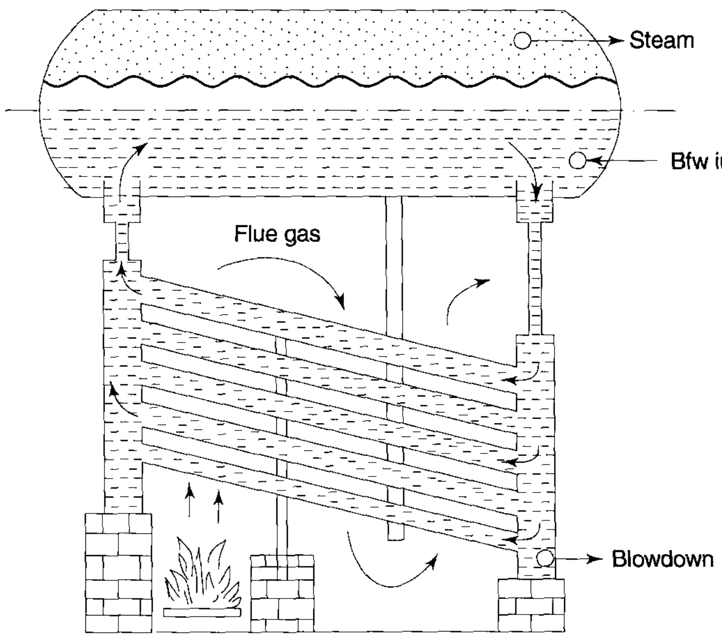

Fig. 1.9 *Horizontal boiler*

A horizontal boiler has its principal axis horizontal or slightly inclined while that of a vertical boiler is perpendicular to the horizontal plane.

Q. *What is a single tube boiler?*

Ans. A boiler having only one firetube is called a single tube boiler. (CORNISH or simple vertical boiler).

Q. *What is a multitube boiler?*

Ans. A boiler having two or more fire or watertubes is called a multitube coiler.

Q. *How can boilers be classified on the basis of use?*

Ans. This is done on the basis of the nature of service they perform. Customarily boilers are called

(a) **stationary:** these are land based boilers.
(b) **mobile:** these are mounted on marine vessels and steam locomotives.

Q. *What is a stationary boiler?*

Ans. This boiler, as its name implies, is not required to be transported from one place to another.

Q. *What are mobile boilers?*

Ans. Locomotive and marine boilers, which are moved from place to place, are mobile boilers.

Q. *How may stationary boilers be classified further?*

Ans. They can be classified further depending on the specific service they meet:

1. Stationary boilers for central station (district) heating
2. Stationary boilers for process steam generation
3. Stationary boilers for power generation.

Stationary boilers used for heating are often classified as:

1. Residential boilers
2. Commercial boilers.

Q. *How can boilers be classified on the basis of furnace position?*

Ans. Depending on the relative location of the furnace to the boiler, the boiler classification can be made by:

1. Externally fired furnace
2. Internally fired furnace.

Q. *What is the difference between externally fired and internally fired boilers?*

Ans. In the case of externally fired boilers, the combustion of fuel takes place in a chamber outside the boiler shell while in the case of internally fired boilers, the combustion chamber is provided inside the boiler shell.

Q. *How can boilers be classified on the basis of tube contents?*

Ans. Depending on whether the flue gas or water is in the tube side, boilers can be classified as:

1. Firetube boilers
2. Watertube boilers.

Q. *Give some examples of firetube boilers.*

Ans.
1. Locomotive boiler (Fig. 1.10)
2. Cochran boiler
3. Cornish boiler.

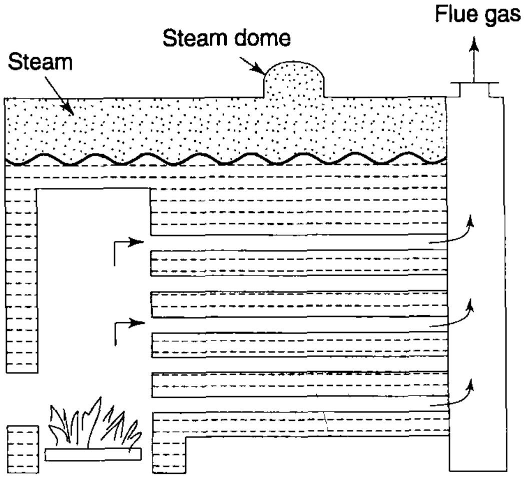

Fig. 1.10(a) *Locomotive boiler: gas flow circuit*

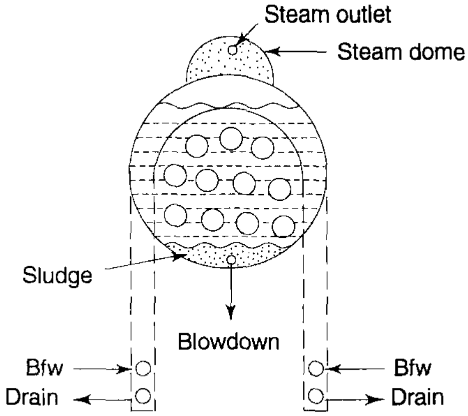

Fig. 1.10 (b) *Locomotive boiler: water circulating system*

These have hot flue gas in the tube side and BFW in the shell side.

Q. *Cite some examples of watertube boilers.*

Ans.
1. Babcock and Wilcox boiler
2. Stirling boiler
3. La Mont boiler
4. Yarrow boiler.

All these have BFW in the tube side and hot flue gas in the shell side.

Q. *What are the comparative advantages and disadvantages of firetube and watertube boilers?*

Ans.

Parameters	Firetube boilers	Watertube boilers
1. Rate of steam generation	Less rapid	More rapid
2. Suitability for power plants	Unsuitable	Suitable. All major power plants are based on these.
3. Operating steam pressure	Limited to 25 kgf/cm^2	Can well exceed 125 kgf/cm^2
4. Chances of explosion	Less	More
5. Risk of damage due to explosion	Much more	Much less
6. Water treatment	Not very necessary as minor scaling would not go far enough to cause overheating and tube-bursting	Required as scaling will lead to tube-bursting
7. Floor space requirement	Much	Less
8. Cost and construction problem	Higher	Much less
9. Transportation	Inconvenient due to large size of the shell	Comparatively easier
10. Skill required for efficient operation	Less	More

Q. *How many types of watertube boilers are there?*

Ans. Two. Straight tube and bent tube boilers.

Q. *On what grounds are bent tube boilers more favourable than straight tube boilers?*

Ans.
1. Bent tube boilers lend greater economy in fabrication and operation than straight tube boilers. These are due to the use of welding, improved quality steel, waterwall construction and new manufacturing techniques.
2. Bent tube boilers afford greater accessibility for inspection, cleaning and maintenance due to more spacious layout of tubes.
3. They have a higher steam generation rate than straight tube boilers
4. They produce drier steam than straight tube boilers.

Q. *What are the essential qualities of a good boiler?*

Ans.
1. It should be capable of quick start-up