Material Handling Systems Design for Process Industries with Special Reference to Pulp and Paper Industry

RAO N.J.*

Ever since the beginning of time Man has been faced with the problem of moving himself and materials needed for his existence Movement is the common denominator of all economic activities involving physical goods and in much that supports intellectual activities. Man is the material handler in daily life. Application of the mechanical principles such as the lever, the wheel, the pulley and the inclined plane make the job of moving, lifting and carrying easier, faster and safer. Basically material handling is the lot of implement movement economically and safely. It is only since world war-II that this has been recognized as a basic industrial task.

Material handling is handling materials

Material handling is Motion, Time, Quantity and Space. In manufacturing there are primarily 3-basic functions namely (a) work performing functions which alter materials (b) Handling functions which move and store materials and (c) Control functions. Material handling is the act of creating time and place utility as distinct from manufacturing which creates form utility. Movement over long distances i.e. tranportation has received attention while movement over short distance namely material handling has not received the due attention. Range of material handling activities includes work place movements, times movements, inter departmental and intra departmental movement, inter plant transfers, inter company movement and systems movements. The material handling activist is involved in such diverse functions as packaging, loading and unloading, transportation, storage, issue in process handling etc.

The benefits of the better material handling include replacement of human efforts for easy and better performance of jobs including overall cost reduction. The objectives include - reduction of costs through reduction of material handling and storage costs or to reduce total production cost. This results from reduced material handling labour, reducing wastes and damage, reducing paper work, reduced in-process storage.

— Increased Capacity due to better space utilization, improving layouts and reduced travel, higher equipment utilization, faster loading and discharging.

— Improved working conditions by safety to men, material and equipment, easier jobs; lighter work and fool-proof operations.

— Improved salability of a product by speed of service, helping customers to cut costs.

It must be remembered that adopting new material handling systems might mean additional capital investment, loss of flexibility and vulnerability to break down, increased maintenance cost. However adopting new systems must be carefully analysed from all angles to find overall suitability. Material handling is related to other organisational functions namely purchasing, inventory, production control, plant layout. Infact material handling and plant layout are very closely inter-related. The objectives of material handling associated with each plant layout objective are listed in table—1.

*Professor & Director,
Institute of Paper Technology, Saharanpur-247001.

Table—I

Objectives of Plant Layout and Material Handling

1.	Facilitate the manufacturing process. a Efficient flow of materials b. Minimum production bottlenecks c. Quicker delivery to customers
2.	Minimum material handling a. Larger unit loads b. Less damaged material c. Better control of materials d. Automatic/Mechanized handling.
3.	Maintain flexibility of arrangement and operation a. Flexibility of handling methods and equipments. b. Co-ordinated material handling systems. c. Material handling planned for expansion.
4.	Maintain high turn over of work-in-process a) Shorter production time cycles b) Constant rate of production
5.	Hold down investment in equipment a) Less idle time per machine b Reduce handling between operations
6.	Make economical use of floor area a) Better space utilization b) Higher production per unit area per employee c) Use of material handling equipment not requiring fixed floor space
7.	Promote efficient utilization of manpower a) minimise manual handling b) Make effective use of containers
8.	Provide for employees convenience, safety and comfort. a) Safer working condition b) Less fatigue c) Improved personal comfort d) Upgrading of employees.

Basis for material handling analysis :

With continued squeeze on profits and rising competition, the paper industry has to take a first look on material handling systems to reduce production costs. The analysis will depend upon type of company, products manufactured, size and value of products, and complexities involved. Integrated, material handling plans have to be developed. The material flow cycle or the process flow systems will dictate the cycles and sub-cycles present and material handling required.

How shall the improvement of specific material handling situation be approached ? The common error is to assume some kind of equipment will solve the problem. It is the beginning at the wrong end. The material handling problem, for it is starting with an answer, rather than with the problem. First question is why it is necessary ? A simple unsophisticated yet useful way to keep material handling study in perspective is the material handling equation shown in Fig. 1

Once such an equation is established it becomes easy to sort out the problem and seek an acceptable solution.

Material handling systems have primarily been designed for engineering industries. The concepts are extended to process industries. There are some significant differences between engineering and process industries. Engineering indussry is essentially an assembly line manufacturing unit where components are handled as discrete pieces and move from stage to stage where various transformations (essentially physical) are brought about or where sub assemblies of component are carried out Here each discrete components is handled as a unit and activities performed before the next piece is tackled.

On the other hand in a process industry, the transformation (Physical or chemical) are brought about as the material moves from stage to stage. Whether they are handled in batches (as in a digester) or in continuous processing units (as in dryer) the materials processed are as purely bulk or continuous mass and are not handled single discrete/component unit. The concept of assembly line does not hold good here. The processing materials, solids or fluids or a combination has to be handled as flow systems or as batch systems with no defined shape or size. These characteristics make the material handling extremely difficult and complicated. In general, development of suitable material handling systems for process industries has been attempted on the experience and basis of engineering assem-

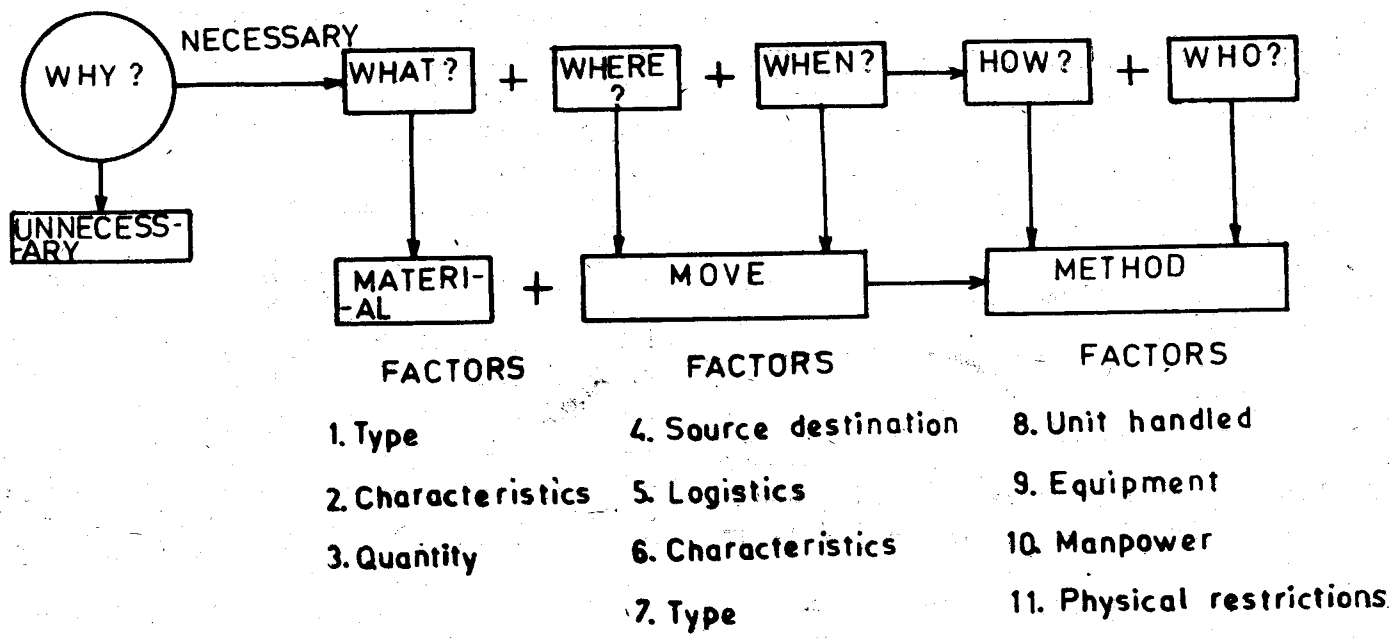

Fig. 1 MATERIAL HANDLING EQUATION

bly line industry with a result that such systems seldom functioned satisfactorily.

The Chemical process industries like Pulp and Paper Industry have some major characteristics. These include.

a) Handling/processing of solids, liquids and gases as single components or in various combinations

b) The processing is done either/in batches or in continuous units.

c) The materials handled in bulk seldom have a shape or a size of their own They are loose.

d) Being a continuous Mass, (though some times containing discrete solid particles) these change their shape during flow or processing, thus aften requiring close conduit flow.

e) Gases and most liquids need always close conduit flow.

(f) Process Control demand intermediate storage or inventory and their movement and storage are accomplished by storage tanks (open or closed) and pumping systems.

g) The flow from storage units, bins, hoppers of solid, semi solid material as a continuous mass often poses problems of feeding due to stickiness, arching and lump formation and casing tendencies. The materials may be free flowing, abrasive corrosion, dusty, fluffy or aerated. These need special considerations.

h) In many stages of processing the solid materials/products handled are in long continuous form (like paper sheet/roll) where handling requirements are significantly different from conventional discrete solid handling. The situation is simplified once it is made into a roll or a packet and handled as a unit load.

i) Use of moblie small material handlers like trolleys/fork lift trucks are not suitable to handle fluids/flu-osolids systems till they are containerized.

Principles of material handling—

The general guide to material handling is based on experienced analysis of situations. The principles are briefly as under :

i) Planning Principle — All handling activities should be planned. It should not be left to chance, and 25–80% of all productive activity may be handling activity.

ii) Systems Principle - Plan a system integrating as many handling activities as possible and co-ordinating the full scope of operations. Isolate spot solutions may not be the best answer.

iii) Material flow Principle - Plan an operation sequence and equipment arrangement to optimise material flow. This is determined by operation sequence.

iv) Simplification principle — Reduce, combine or eliminate unnecessary movements and/or equipments. This will bring in efficiency, economy of motion.

v) Gravity Principle — Utilize gravity to move material whenever practicable.

vi) Space utilisation principle — Make optimum utilization of building Space

vii) Safety Principle — Provide for safe handling methods and equipment. Causes of accidents could be unsafe conditions (environmental), unsafe acts of persons and unsafe personal causes.

viii) Mechanisation/Automation Principle - Use mechanised or automated material handling equipment when practicab'e

ix) Equipment selection Principal — In selecting handling equipment, consider all aspects of the material to be handled the move to be made and the method to be utilized.

x) Standardization Principle — Standardize methods as well as types and sizes of handling equipment.

xi) Flexiblility Principle — use methods and equipments that can perform a variety of tasks and applications

xii) Dead weight principle — Reduce the ratio of mobile equipment dead weight to pay load.

xiii) Motion Principle — Equipment designed to transport material should be kept in motion.

xiv) Idle time Principle – Reduce idle time or unproductive time of both handling equipment and manpower

xv) Maintenance Principle — Plan for preventive maintenance and scheduled repair of all handling equipment.

xvi) Obsolescene Principle — Replace obsolete handling methods and equipment when more efficient methods or equipment will improve operations.

xvii) Control Principle — Use material handling equipment to improve production control, inventary control and order handling.

xviii) Capacity Principle—Use handling equipment to help achieve full production capacity.

xix) Performance Principle - Determine efficiency of handling performance in terms of expenses per unit handled.

These principles should be utilized effectively by means of check sheets for each interest area like storage and ware housing manpower or material handling.

Unit size Princip'e suggests "larger the load (Unit load), the lower the cost per unit handled". This would mean what is the right size for a package or load. The unit load principle implies that this material should be handled in the most efficient, maximum size unit using mechanical means to reduce the number of moves needed for a given material. A unit load has been defined as—

A number of items or bulk material so arranged or restrained that the mass can be picked up and moved as a single object too large for manual handling and which upon being released will retain its initial arrangement for subsequent movement. It is implied that single objects too large for manual handling are also regarded as unit loads.

The advantages of unit loads include handling larger loads at reduced costs with faster movement, reduced loading/unloading and packing costs, gives maximum use of cubic space besides reduced damage and safer handling. The limitations are costs of unitizing/de-unitizing, reduced flexibility.

The basic ways to move a unit load are :

i) A lifting device under the mass.

ii) Interesting a lifting element into the body of the unit load.

iii) Squeezing the load between two lifting surfaces.

iv) Suspending the load.

There are 5 well defined unit load techniques :

a) Unit load on a platfarm-solid, pallet.

b) Unit load on a sheet - flat sheet of card board, ply-board etc, moulded sheets, flexible sheet used as a slug between the forks.

c) Unit load on racks - with wheels or trays.

d) Unit load in container - Full or partial enclosure to suit requirements such as a box, bin, crate or balloon.

e) Self contained unit load - not requiring auxiliary aids like bundle, bale, fastened unit load, interlocked unit load.

The efficiency of unit load in terms of utilization can be found to help in proper selection. The concepts can be extended to certain extent for process plants where the handling is In form of bales, drums, bins.

Equipment Concepts :

Successful solution of material handling problems involves a proper matching of material characteristics, movement requirement and method (equipment) capabilities. This must be with in the existing or conemplated physical facilities and environment and against related costs. Equipment is not always the solution to material handling problems. Mannual handling may be the easiest, most efficient and least expensive method of moving materials. For unit material of small size, light weight and fragile nature with logistic small movement, manual methods may still be the best. Non powered equipment or mannually operated equipment are good where handling volume is limited, where heavier devices cannot be used, where capital availability is limited or where flexibility is required. Otherwise powered equipment are necessary for material handling

The development of a material handling system for a process industry has to be based on the information and knowledge of the processing scheme, the sequencing of the processing equipment, the flow of materials and possible equipment layout, location and sizes. Chemical processing plant handle solids, liquids and gases and a combination of these. The material handling systems are designed based on the characteristics of the material to be handled, its quantity, distance to be transported and other environmental factors and location factors. The material handling systems in a process can be broadly classified as under :

a) Handling of fluids
b) Handling of solids

4.1 Handling of Fluids :

Liquids and gases are handled in large quantities and design procedures are available for simple systems. The fluids are newtonian or non-newtonian. The flow of all single phase homogeneous, non-newtonian fluids and multiphase fluids, gasliquid, liquid-liquid, liquid-solid, gas-solid or combination is complex. The broad classification of complex mixtures from the point of view of flow behaviour is shown in Fig 2, Fig. 3. indicates the behaviour of time independent viscous

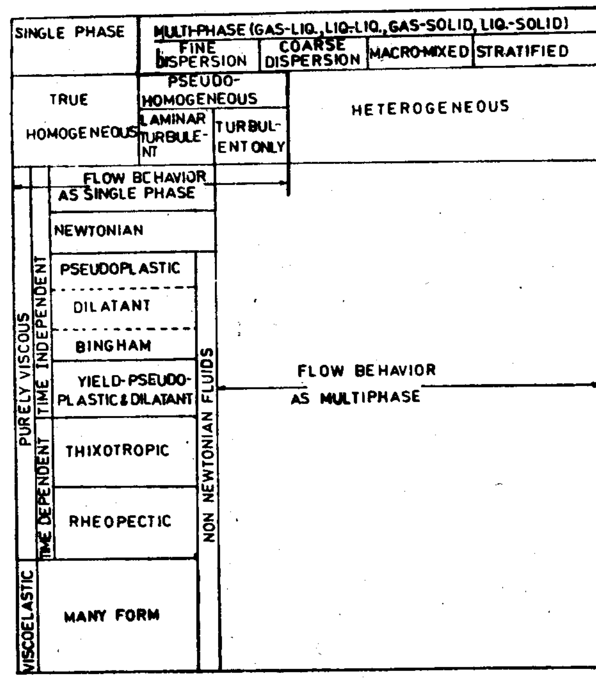

Fig. 2-RHEOLOGICAL CLASSIFICATION OF COMPLEX MIXTURES

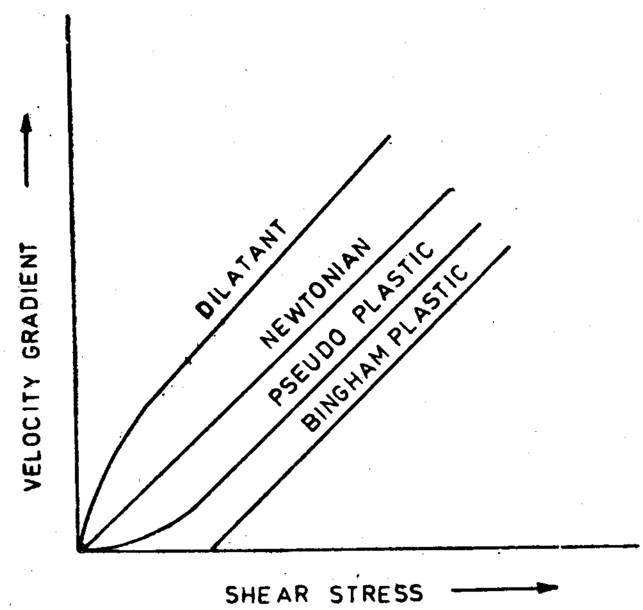

Fig. ?—BEHAVIOUR OF TIME INDEPEDENT FLUIDS

fluids. Purely viscous fluids are those which on removal of the shearing force do not recover from any deformation, they may have undergone. Visco-elastic fluids are those which on removal of shearing force do, in part recover from deformation. Visco elastic fluids are in between purely viscous fluids and purely elastic solids.

Table 2 gives the general behaviour of various fluids with a few examples. Understanding of the rheological behaviour is essential in the proper design of transfer lines.

Table—2 : Rheological Behaviour of Fluids.

Time in—dependent (Steady State)	Newtonian	$-\eta$ is independent of shear rate (same as viscosity) (gases, non-colloidal liquids, pure solutions)
	Pseudoplastic	η decreases with increasing shear rate (Paper-Pulp suspension, Gypsum slurry, Rubber, Black liquors, (Soft wood).
	Dilatant	η increases with increasing shear rate (Heavy Starch suspensions quick sand, Suspension of TiO_2, Ultrafine particle suspensions.)
	Bigham plastic	Remains rigid when shear rate is of smaller magnitude than the yield stress and there after behaves like a newtonian fluid (Colloidal clays, muds, Bitumen, hydrocarbon greases, water suspension of fly ash, Sewage sludge, synthetic wax suspension, Aqueous suspension of coal char.)
Time dependent (unsteady state)	Thixo tropic	Limited decrease in η with time under a suddenly applied constant stress. It passes through a minimum (Bentonitic clay suspension, petroleum crudes; pulp suspensions, Black liquors (Soft wood).
	Rheopectic	Limited increase in η with time. It passes through a maxima. (Less common. High molecular weight polyester, Black liquors, (Mixed Hardwood).
	Visco-elastic	Fluids partially return to their original form When applied stress is released (molten polymers, long chain molecules like polyethylene oxide, sodium carboxy methyl cellulose solutions)

*Steady state rheological behaviour of most fluids Time-independent) is indicated by the correlation

$$\zeta = -\eta \frac{dv_x}{dy}$$

ζ—Shear stress, η —apparent viscosity

$\frac{dv_x}{dy}$ — Velocity gradient

Multiphase mixtures under flow conditions can be qualitatively described as a fine dispension as small bubbles of gas, droplets of immiscible liquids or particles of solid in a continuous liquid/gas phase, a coarse dispersion (as large bubbles of gas, drops of an immiscible liquid or particles of solids in cotinuous liquid/gas phase), a macro mixed flow pattern (as froth or highly turbulent mixture of gas and liquid or immiscible liquids where neither phase is continuous) and a stratified flow pattern (in fluid-fluid systems, both phases and continous). In such mixtures phase separations can occur due to setting behaviour. Terminal settling velocity of solid particles and fluid particles can be determined. These values get effected due to tube wall (wall effect) or due to concentration (Hindered settling). The fluid-fluid, fluid-solid dispersions may behave as a pseudo homogeneous fluid depending on the degree of turbulence and phase separation velocity. These in turn depend on particle and fluid characteristics and concentrations.

Two phase flow systems are much more complicated, gas-liquid Co-current flow with constant or varying gas-liquid ratios are encountered in many practical situations Reliable co-relations are yet to be developed for production of pressure drops, volume fractions or hold ups and flow pattern in pipes.

The flow of two phase systeme can be broadly classified as under :

a. Vertical flow of gas-liquid and liquid-liquid mixtures in pipes

b. Horizontal flow of gas-liquid and liquid-liquid mixtures in pipes.

c. Vertical flow of gas-solid and liquid-solid flow in pipes

d. Horizontal flow of gas-solid and liquid-solid mixtures in pipes.

Vertical flow of gas-liquid and lipuid-liquid mixtures :

This is widely encountered in petroleum industry, chemical processing industry, steam generation equipments and nuclear reactor design. Gas-liquid flow is encountered in heat transfer where partial vapourisation starts. The problem becomes complicated due to continuous charge of proportions of gas and liquid. The flow patterns in such up flow systems is shown in Fig. 4 and table 3. At low liquid velocities as the gas rate is increased (O to 0.6 M/sec.), the gas is dispersed as discrete bubbles which increase steadily in numbers and with coaleseence may increase in size. This is the bubble flow pattern. With further increase in gas flow, bubbles coalasce to form large cap shaped bubbles nearly spanning the tube marking the on set of slug flow. At still higher gas velocity, bubbles become unstable, and collapse under the flowing liquid pressure gradient. This leads to "froth flow", a highly turbulent coarse agitation of liquid flow. At further increase in gas flow, the liquid distributes itself between an upmoving wavy orripply layer of liquid on tube wall and coarse drop-lets carried in the continuous gas phase. At slightly higher gas velocities, the liquid film becomes steady giving annular flow, Finally at very high gas flow, water gets dispersed as drop lets leading to mist flow. The generalised fllow pattern map is shown in Fig. 5.

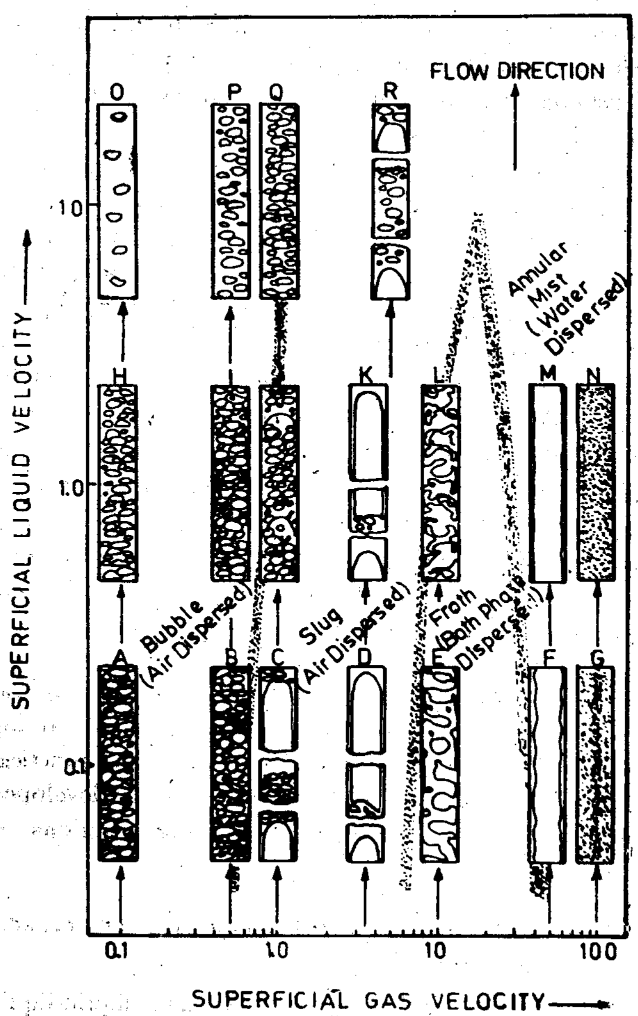

Fig. 4—FLOW PATTERN OF GAS LIQUID MIXTURES FLOWING IN A VERTICAL PIPE

The liquid hold ups ratio (Gas/liquid) at constant liquid velocity increases with increase in gas velocity passing through a maxima in froth regime and decreasing in annular and mist flow regimes. Pressure gradients first decrease going through a minima, then increase, passing through a maxima and once again pass through a minima before rising with increasing gas velocity for a given liquid velocity. Similarly rise velocity of bubbles, effect of tube wall, pattern of slugs, transition to forth flow and on to annular and annular mist flow, can perhaps be predicted.

Horizontal flow of gas-liquid and liquid-liquid mixtures in pipes.

Horizontal flow of gas-liquid and liquid-liquid mixtures is quite common in pipe flow particularly in case of liquid and gaseous hydrocarbons, in evaporator operation, chemical reactors, heat exhangers in boilers, condensers, refrigeration and air conditioning equipments. In these la er cases besides pressure drops or hold up, heat transfer rates are important and they get influenced by flow patterns prevelent. The flow patterns will depend on the system (Gas-liquid or liquid-liquid systems), their velocities and the physical characteristics. Typical flow patterns for gas-liquid flow in horizontal pipes is shown in Fig, 6. At lowest liquid flow rate, four different flow patterns may be distinguished i.e. Stratified-Smooth interface; Stratified-ripply

Table—3 Flow regimes in two phase gas-liquid flow in vertical pipes (liquids of viscosity less than 100 C.P. and gas of density about that of air)

Sl. No.	Type of flow	Flow characteristics	Superficial velocity m/s Liquid	Gas
1.	Bubble or aerated flow	Gas dispersed as fine bubbles	1—3	Below 0.6
2.	Piston, Plug or Slug flow	Gas flows as large plugs	1—3	0.6—0.9
3.	Froth flow	Gas bubbles mix with liquid in highly turbulent pattern		1—8
4.	Ripple or Wave flow	There is an upward moving wavy layer of liquid on wall		7—9
5.	Annular or film flow	Liquid flow up as annulus and gas flows in core	Less than 0.6	Over 9
6.	Mist flow	Liquid flows as fine drops in gas		Over 21

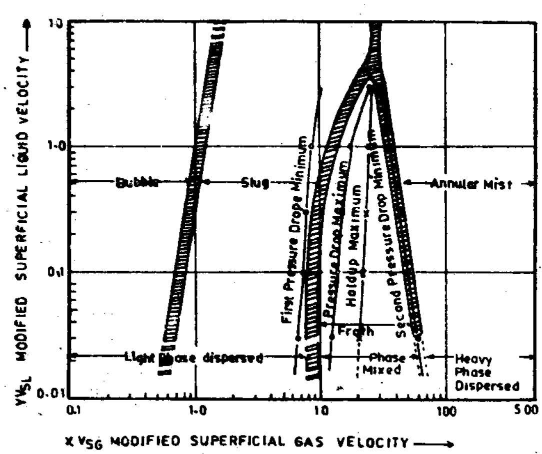

Fig. 5- GENERALIZED FLOW PATTERN MAP FOR FLOW OF GAS LIQUID MIXTURES IN VERTICAL PIPES

$$Y = \left[\frac{\text{DENSITY OF LIQUID}}{\text{DENSITY OF WATER}} \cdot \frac{\text{INTERFICIAL TENSION OF AIR-WATER}}{\text{INTERFICIAL TENSION OF LIQ.-GAS}}\right]^{1/4}$$

$$X = Y\left[\frac{\text{DENSITY OF GAS}}{\text{DENSITY OF AIR}}\right]^{1/3}$$

V_{SL} – SUPERFICIAL LIQ. VELOCITY

V_{SG} – SUPERFICIAL GAS VELOCITY

interface, Wave and annular-mist flow, each occuring at successively higher gas flow rates. At intermediate liquid rates, the stratified and Wave flow patterns are replaced by elongated bubbles flow pattern and the slug flow pattern. At the lowest gas velocities discrete elongated gas bubbles ride in the upper portion of the pipe. At modest gas velocities these agglomerate to form the distorted equivalent of smooth cylindrical bubbles. With further increase in gas flow, the rounded non elongated bubbles become even longer and occupy a greater cross section area and suffer further distortion. They are separated by slugs of liquid, some times containing entrained gas bubbles. Eventually with further increase in gas velocity annular-mist flow pattern sets in. At the highest liquid rates and low gas rates, gas bubbles are distributed almost uniformly throughout the liquid. Giving the dispersed bubble or bubbly flow pattern; Table—4 gives the flow regimes alongwith their characteristics. The behaviour is slightly different for liquid-liquid systems.

The flow pattern map for horizontal flow of liquid is shown in fig. 7.

The hold up ratio (gas/liquid) at a particular liquid velocity increase with increasing gas velocity reaching

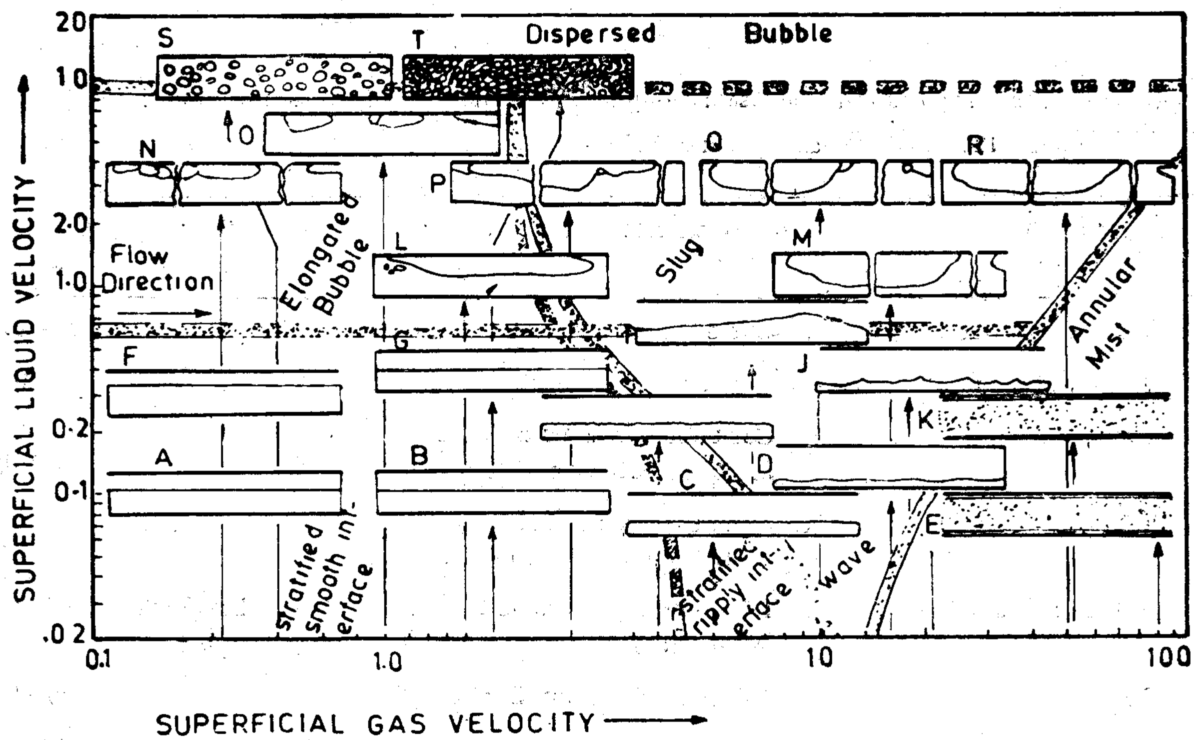

Fig. 6. FLOW PATTERNS OF GAS LIQUID FLOW IN A HORIZONTAL PIPE

NOMENCLATURE :-

A,B,C,F,G,H.	Stratified
D,I,J.	Wave
E,K.	Annular Mist
L,N,O.	Elongated Bubble
M,P,Q,R.	Slug
S,T.	Bubble

a maxima, there after decrease slighly going through a minima and increasing once again. At a given air velocity, hold up ratio increases with decrease in liquid velocity. Pressure gradients increases, slowly first, and sharply later with increasing gas velocity for a given liquid velocity. At a given gas velocity, the higher is the pressure gradient with increasing liquid velocity. The situation will become even more complicated when pipes are inclined.

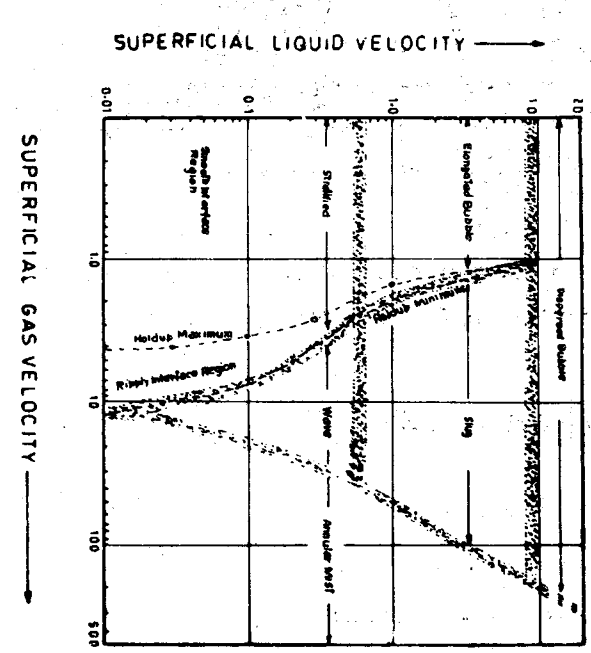

Fig. 7—FLOW PATTERN MAP FOR GAS-LIQUID MIXTURES IN HORIZONTAL PIPE.

Table—4 Flow regimes of two phase liquid-gas flow in horizontal pipe (for liquids of viscosity less than 100 Cp and gases of density about that of air)

Sl. No.	Flow regime	Characteristics	Superficial velocity Liquid m/s	Gas m/s
1.	Bubble or froth flow	Bubbles of gas dispersed throughout liquid	1.5—4.5	0.3—3.0
2.	Plug Fow	Alternate plugs of gas and liquid move	Less than 0.6	Less than 0.9
3.	Stratified flow	Liquid flows along bottom of pipe and gas flows over, smooth liquid gas interface	Less than 0.15	0.6—3
4.	Wavy flow	Similar to stratified flow, but gas liquid interface Wavy	Less than 0.3	About 4.5
5.	Slug flow	A wave is picked up periodically by the rapidly moving gas to form frothy slug which moves at greater velocity than liquid-causes high vibrations,	—	—
6.	Annular flow	Liquid flows as an annular film with gas flow in the core	—	6
7.	Spray or dispersed flow	Liquid entrained as droplets in a gas	—	60

4.1.3 The Vertical flow of gas - solid and liquid - solid mixtures in pipe.

Vertical pipe line transport of fluid-solid mixtures is being used with greater frequency in process industries. Some times solids are added to flowing fluid streams to control scale deposition and to enhance convective transport by increasing the intensity of turbulence. The information to predict flow patterns, hold ups and pressure drops in vertical flow fluid-solid mixture is limited. Fluidization and settling are comparatively better understood. If a fluid-solid mixture is introduced in a system at a velocity below the velocity at which steady state condition is possible, the system will eventually choke with accumlation of solids. Prediction of choking or minimum transport velocity is important in design of vertical transport system. The loading ratio or the solids to fluid ratio is another important parameter in design.

The flow pattern in up flow fluid-solid mixtures has solids indispersed state with concentration profiles symmetrical about pipe axis. The hold up data in these system is inadequate. Hold up ratio (fluid/solid) decreases with increasing mixture velocity. It must be remembered that there is slip between solid and fluid and slip velocity is equal to or greater than terminal setting velocity. The pressure gradients decrease with increasing mixture velocity passing through a minima and there after goes up again. The higher the input friction of solids, higher is the pressure gradient.

Horizontal flow of gas-solid and liquid-solid mixtures in pipes.

Hydraulic transport of solids is followed commercially for quite some times. Dilute water suspension of pulp fibre are transported in pipes. Pneumatic conveyance of finely divided solids and hydraulic transport of wood chips are areas receiving attention.

The flow behaviour of fluid solid systems depends on physical properties. relative solid-fluid amounts and size and shape of particles. Fibres before significantly differently from granular solids. Ultrafine particles (below 10 micron) are always carried fully suspended with negligible gravity effects. Fine particles (10 100 microns) are carried in a fully suspended state with concentration gradients due to gravity. Medium sized particles (100-1000 microns) are suspended at higher velocities, but will often form a moving deposit on pipe bottom and concentration gradient will exist. Coarse particles (1000—10000 microns) will from a moving deposit. Ultra coarse particles (above 10,000 microns) are seldom suspended at normal velocities.

The flow pattern for fluid-solid systems in horizontal flow has distinct patterns at different velocities and concentrations as indicated in the table—5

Table—5 Fluid-solids flow in horizontal pipes.

System	Conditions	Flow Pattern
Liquid-solid	Highest mixture velocity (3m/sec or more) Fine/medium particles fully suspended.	Symmetric concentration profiles even at 1-2 m/sec. if turbulence is present. This will persist at higher velocity.
	Medium velocities, low turbulence	Solids tend to settle, distorted concentration profile with larger particles tending to settle in bottom half of pipe. Asymmetric suspension flow will be present. Some particles will strike the pipe wall.
	Low Velocity	Particles accumulate, first form separated dunes and then form moving beds.
	Still lower velocity	Lower most particles stationary, bed thickens. Saltation results, Cross section for flow decreases with a symmetric suspension in narrow top zone.
Gas-soltd systems	Low density flow (dilute phase flow ratio of solid/gas less than 10) High gas velocity (20m/sec. and above) small particles,	Symmetric suspension
	Loading 10-20, low gas velocity	Density variation sets in. Moving bed pattern with saltation sets in. Initially solids bounce from wall.
	High loading (Dense phase)	Solids settle at bottom form dunes and may form slugs,

Hold up ratio (fluid/solid) decreases with increasing mixture & velocity. However slip will be present. Pressure gradients first decrease and then increase with increasing mixture velocity only after passing through a minima. There is no single correlation available for predicting the minimum carrying velocity for all solid to gas ratio in horizontal pipes. Pressure drop in such lines is considered as the sum of the component pressure drops. For solids to gas weight rate ratio of less than 5, horizontal pipe lines are treated as pneumatic conveying systems. For solids to gas weight rate ratio of over 50, (Dense phase transport) particles tend to settle down and the estimations become complex Similarly checking imposes limitations on the pneumatic transport lines This occurs at a critical volume fractions of solids at which particles tend to agglomerate and large unsteady pressure gradients are generated There are few correlations to predict saltation velocities.

Handling of solids :

Solids material handling equipments can be further devided into :

a) Those which transfer.

b) Those which feed.

c) Those which store.

The three basic type of material transfer/handling equipments are conveyors, cranes and Hoists, and trucks. The primary function of a conveyor is to convey uniform load continuously over fixed path, While cranes/Hoists transfer varying load intermittently over fixed path and industrial trucks monorver and transport mixed loads intermittently over various paths Normally all these activities are over short distances and inside factories.

1) The general characteristics of basic solids material handling equipments are shown in Table 6

The equipment can be considered from the following angles.

a) Equipment oriented system—like industrial trucks, pallet systems, tractor - trailler system, conveyor system or overhead systems.

b) Material (Load) oriented systems - like unit handling system, bulk handling system, liquid handling system.

TABLE—6

General characteristics of basic solid material handling equipment type

	Task & Equipment Characteristics	Epuipment Type	Conveyors	Cranes & Hoists	Industrial Trucks
Material	1. Volume		High	Low, medium	Low, medium, relatively
	2. Type		Individual item, Unit load, Bulk	Individual item, Unit load (variety)	Individual item, Unit load, variety
	3. Shape		Regular, uniform irregular	irregular	Regular, uniform
	4. Size		Uniform	mixed, variable	mixed, uniform
	5. Weight		Low, medium, heavy, uniform	heavy	medium, heavy
Move	1. Distance/speed		Any/uniform or variable	Moderate/variable	Moderate/variable
	2. Frequency		Continuous	Intermittent	Interminent
	3. Destination		Fix d	May vary	may vary
	4. Area covered		Point to point	confined to area within rails	variable
	5. Path		Fixed	May vary	variable
Method	1. Load support method		None or in containers	Suspension, pallet, solid, none	From beneath, Pallet, solid, container
	2. Load/unload characteristics		Automatic, manual designated points	Manual, self, any part	Self, any point on available path.
	3. Operator accompanying the load		No	May or may not, usually docs	usually does
Building Characteristics.	1. Cost of floor space		Low, medium	High	medium, high
	2. Clearing height		If enough, conveyor can go over head	High	Low, medium, high
	3. Running surface		N.A.	N A.	Must be suitable
	4. Aisle		N.A.	N A.	Must be sufficient
	5. Congested areas		Fair	good	Poor

c) Method (Production) handling system—like manual, mechanised, automated, mass production handling, job shop handling, Continuous systems.

d) Function oriented handling systems - like transportation systems, electing systems, conveying systems, transferring systems, self loading systems.

Conveyance of solids :

The conveyance of bulk solids is a major area in Process Industries. The equipment for transportation of solid can be classified as shown in Table—7.

Table 7 : Conveying and Elevating Devices.

I. Conveyors that carry
   A. on upper surface or in Pans
      i) Belt conveyors
      ii) Slat, Apron, and Pan conveyors
      iii) Pivoted - Bucket conveyor
      iv) Vibrating Conveyor
      v) Gravity roller conveyor
   B. Inside closed tubes
      i) Tipper conveyor
   C. By suspension from above
      i) Chain conveyors
      ii) Overhead mass rails

II. Conveyors that drag on Push
   A. Dragor Flight conveyor
   B. 'Enmasse' conveyors
   C. Screw and Ribbon Conveyor

III. Conveyors depending on fluidization
   A. "Boiling bed" type
      i) Air slide
   B. Pneumatic conveyors
      i) Vacuum systems
      ii) Pressure systems

IV. Elevators
   A. Bucket elevators
      i) Centrifugal discharge
      ii) Positive discharge
      iii) Continuous bucket type
   B. Pivoted-bucket conveyor-elevator
   C. Zipper conveyor elevator
   D. Screw elevator
   E. 'Enmasse' elevator
   F. Pneumatic conveyor-elevator

Area of conveyance of solids is dealt in detail in many texts on material handling. Chutes or a slide is made to glide the material by gravity in inclined planes or as spiral between extreme levels.

Discharge and Feeding of solids :

There are two forms of high bulk density flow (i) Stick-slip flow and (ii) Aerated flow. Stickslip flow is a jerky movement of compacted grains with velocity of the particles at the wall slightly lower than in the rod-like core. It occurs in downward solids flow with large particles. Sand, Socony beads. flow in this manner in vertical pipe lines. Stick slip flow is concerned with flow in stand pipes and transport lines connecting vessels and hoppers. In aerated flow, solids are fluidized or suspended in a gas and have high mobility compared to stick slip flow. It is limited to fine particles and can be used for transportation of solids in any direction.

When solids discharge from vertical pipes without aeration with restriction, such as through an orifice, piston like stick slip flow occurs every where except near the discharge point. Here solids funnel out leaving an annulus of stagnant material. The height of this exit region is related to pipe diameter and angle of internal friction. Correlation exist for predicting discharge rate of solids from orifices based on angle of repose, orifices diameter, particle size and density and orifice coefficient. Bed heights usually have no influence on discharge rates.

Solids are usually taken from storage in order to feed them into processing system. Feeding may be continuous or intermittent. The control or quantities may very pricise or rough. Feeding problems are aggravated by the uncooperative nature of most solids. Some solids are free flowing, cool and dry. But many of them are sticky, corrosive, erosive, hot, plastic or pasty, some aerate or flood when agitated. The bin storing material are provided with feeder or flow assister to result in an effective mass flow type characteristics. These flow assisting devices feeders can be catagcrised as under :

a) Vibrating hoppers – used to enlarge the storage bin opening and cause flow by breaking up the material bridges. The vibration can be gyratory or whirl pool type.

b) Screw feeders – use of variable pitch screw produces uniform material flow. The screw feeder opening to diameter ratio is kept below 6.

c) Belt or Apron feeders – Care is taken to avoid dead spots in flow channel above. For non - free flowing material, sloping sticker plate is used.

d) Table feeders – The skirt is raised in a spiral pattern for increased capacity in the direction of rotation.

e) Vibratory feeder – The distance between the feeder pan and hopper is increased in the direction of feed.

f) Star feeder – Provides highly uniform with drawl along the slot opening.

Rotating arm units and air fluidizing pads also help in aiding solids flow.

Cranes and hoists, industrial vehicles as material handlers are widely discussed in books on material handling.

The areas which need study relate to bulk handling of materials particularly those which are non free flowing, tending to arch or stick. The areas of screw conveyors, hydraulic and pneumatic conveyors and solid feeders are not yet well developed.

Material handling in paper industry :—Paper industry is a process industry using large quantities of Cellulosic fibrous raw materials, various chemicals, water, coal and other fuels, steam, air, chlorine, lime etc. The materials are either solids or liquids or gases or a combination of these The material handling situation prevelent are often complex and large volumes of material are handled.

The material handling systems in paper industry includes many complicated situations. Handling of solids is a major area where solids as unit loads and bulk solids are handled. Some are free flowing discrete solids. Others are sticky. Some are granular non-abrasive and non-corrosive while others are corrosive and abrasive. Particles in some cases are granular while in other cases it is a fibre. The flow is some times aerated flow while at other situations it is a slip stick flow with arching, sticking, lump formation and also forming scales. Clays, coal, clean fly ash, lime stone dust, salt cake, starch, talc, wood and bamboo chip can be considered as pulverised granular material, not actively corrosive or abrasive or sticky. Standard bucket elevators, apron conveyors, Continuous flow conveyor - elevators, skip hoists, belt and screw conveyors serve the purpose very well. Wet and moist ash is sticky and abrasive. Handling of pith (moist/wet) is quite tricky. Chemicals (solids) are often Corrosive, sticky and abrasive. Sludges are often most difficult to handle though treated as solids Alum, chalk, clays are abrasive. For sticky materials screw coneyors and special feeders are essential. Basic information on flow characteristrics of many solids like angle of repose, internal angle of friction, friction coefficients, friobility nature, sticky nature is not available and there is a need to generate systematic design data.

In certain stages of processing unit load concepts are used in solids handling particularly as paper rolls, bundles, bales, drums, cases and packets, conveyor, fork lift trucks, hoists are often used in their handling. Many fluids are handled in paper industry. Some are single phase fluids like water and air and their handling and design of transfer pipe lines are simple. Fibre water suspension is handled in various consistencies. This behaves as a pseudo plastic when not stored for long otherwise acts as a Thixo-tropic fluid. This system needs carefull study to generate the flow behaviour data and to help in designing pipe lines as well as predicting energy requirements.

Liquid-solid systems are common in paper industry. These include lime slurry (Pseudo-plastic), starch suspensions (Dilatant fluid), suspension of TiO_2 (Dilatant fluid), Clay suspensions (Bingham plastics fly ash-water suspensions Bingham plastics), Carboxy-methyl cellulose solutions (Viso-elastic fluid) polymeric solutions (Visco-elastic fluids). The rheology in many of these situations is just not understood. Some of these are corrosive/abrasive. Many of these systems tend to settle down and cause scales.

Black liquor is a major material handled which settles, causes heavy scaling and often corrosive. It is a very difficult fluid to handle and behaves as a Thixotropic Rheopectic fluid with rheology of situation being different. Similarly the green liquors and white liquors have vary degree of solids causing settling, stratification, scaling in their handling. Planned experimentation is necessary for proper design of transfer lines handling these fluids.

Sludges are another important area of material handling. The material is highly abrasive and one of the most difficult to handle. At varying moisture contents or as slurry its behaviour is not well understood.

Gas-solid mixtures are encountered in paper industry in pneumatic conveyance of solids (wood/bamboo chips being fed to digester, fluidized coal handling, handling of fly ash from boilers, particulates in flue gases ftom recovery boilers). These 2 phase flow systems in horizontal, vertical and inclined lines pose problems of choking, saltation and settling. Hydro dynamic data is necessary for proper design of these systems.

Gas-liquid mixtures flow is found in chlorine lines, steam-condensate lines, flash handling systems. These are complicated flow situations requiring proper information on flow regimes for design of pipe lines. There are many instances of 3 phase flow in paper industry as in digester operation, evaporator operation, hypo-systems. They are even more complex than 2 phase systems.

Most material handling systems are selected on past experience. The under standing of material handling characteristic particularly those relating to prediction of discharge rates of solids from gravity flow/aerated flow systems, flow of fiber water suspensions, behaviour of various pseudo plastics, dilatant, bingham-plastic, Thixotropic, Rheopectic fluids, flow of fluid solids, gas-liquid systems in borizontal and vertical lines is far from satisfactory. Similarly lot of information is required of areas of feeders, and conveyors. This calls for systematic study to characterize materials and their flow behaviour.

Conclusions :

Most material handling problems are not analysed and are yet solved In entirely too many cases, a superficial review of physical aspects of the problem situation is done and a solution is offered. The systems, particularly those dealing with 2 phases, solids feeding, bulk handling need understanding and basic developments. There is a lot of information gap. There is a tremendous room for improvement. Systematic study of the process and layout are essential in suggesting proper material handling solutions. The procedure to be adopted should consist of the following steps.

a) Definition
- Identify the problem
- Determine the scope of the problem
- Establish objectives
- Define problem

b) Investigation
- Determine data to be collected
- Establish work plant/schedule
- Collect data
- Develop/weigh and analyse da a

c) Solution
- Develop improvements
- Prepare justification
- Obtain approvals
- Revise if necessary

d) Installation
- Work out procedure for implementation
- Supervise installation
- Follow up.

Many of the material handling situations are complex and unique to each unit. The study should start with a sincere effort to understand systems behaviour and rheology. Lot of applied research is essential on this front. Such a study will lead to proper understanding and proper selection/design of transfer systems particularly those in the areas of multiphase flow and complex mixtures flow.

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