1. Read the attached paper from Bulk Solids Handling Vol 4 no 3, Sept 1994 page 583 to 588 - attached. Make sure that you understand each of the circuits present – Figures 1 and 3.

2. Read about systems engineering applied to bulk materials handling. See papers on my website. Discuss the relevance of systems engineering to this project. Not that the proposed system is one of several considered to deliver the requirements.

3. Discuss the purpose of each of the items in Figure 1 – primary crusher, impact hammer, ball mill, slurry pump and recycle circuit, agitated storage tanks, main line pumps, filtering, clarifying and drying equipment.

4. Discuss the purpose of the rheological and flow tests conducted with reference to the Warman papers.
5. Size a suitable Warman pump given the following data for the first pump after the ball mill:

\[ C_w = 50\% , \quad \text{Circulating load back to ball mill} = 125\% \text{ of new feed to mill.} \]
\[ Z_d = 18\ m , \quad Z_s = 4\ m , \]
\[ \text{Valves: 4 only,} \quad \text{Long radius elbows: 4 only,} \]
\[ \text{Material properties: estimate from fig 4 and table 2 of paper,} \]
\[ \text{Feed pressure to cyclone} = 250\ \text{kPa}. \]

6. Note that piston pumps are used for the main lines. Why? Estimate the friction loss in the main pipe run.

7. Check, where possible, and discuss the design parameters for the main pipeline as well as the items of tables 3 and 4. Consider the length of pipe run, the throughput, annual operating hours, power requirements, total head requirements etc.

8. Briefly outline possible alternative systems and comment on their suitability.
Techno-Economic Feasibility of Transporting Limestone in Slurry Form to Feed a Cement Plant at the Foothills of the Himalayas

S.R. Basu and A.K. Saxena, India

Summary
This article describes the techno-economic feasibility study carried out for transporting 2 million t/a of limestone as slurry by pipeline for a cement plant proposed to be located at the foothills of the Himalayas. It describes the various aspects of the study, for example experimental tests, design parameters, pipeline route selection, cost estimates, etc. The article also explains the advantages of the pipeline transportation system under the present situation.

1. Introduction
The Cement Corporation of India Ltd. (CCIL) is examining the possibility of exploiting the limestone deposits located in the Himalayan Ranges, in the Chamk district of Himachal Pradesh. The deposits are currently estimated to have reserves of more than 400 million tonnes. Further geological investigations are in progress and it is expected that the current estimates of the reserves will be increased several times. The above limestone deposits are proposed to be utilised for the cement plant to be located at the foothills of the Himalayas. At present there is a narrow all-weather road linking the deposit with the proposed cement plant site. The distance between the deposit and the proposed cement plant site is 200 km by road and 70 km as the crow flies. The greatest problem in procuring the basic raw material, i.e. limestone, for the proposed cement plant is transportation from the deposit to the proposed cement plant site. The various options available are:

1. Laying a new railway track and transporting the limestone by railway to the cement plant, or locating the cement plant at the mine site and transporting the product.
2. Broadening of road to cater for the enlarged needs of transportation of the limestone to the proposed cement plant, or locating the cement plant at the mine site and transporting the product.
3. Transportation of limestone by means of an aerial ropeway system.
4. Transportation of limestone as slurry by pipeline.

The intervening tract between the cement plant and the mine site is hilly and rugged terrain, and full of jungle. The proposed route is plagued by frequent landslides. Construction of either railways or roadways will face immense problems with respect to money, construction and time. As such, locating the cement plant at the mine site was ruled out. Locating the cement plant far away from the limestone deposits would leave the choice predominantly to the last two options. Option No. 3, i.e., transportation by aerial ropeway, is a viable solution, but a long-distance aerial ropeway does not exist for similar purposes over such terrain anywhere in the country. In view of the above anticipated problems of the other modes of transport vis-à-vis the inherent advantages of the slurry transportation system and in view of the successful operation of Kudremukh iron ore pipeline in the country, CCIL requested that a techno-economic study be made to examine the feasibility of transporting limestone to the proposed cement plant. They assigned Metallurgical & Engineering Consultants (India) Ltd. (MECON) with the task of carrying out this feasibility study.

2. Status of Transportation of Limestone as Slurry through Pipeline
Slurry pipelines are widely recognised today as an economical and reliable mode for transporting various solids over long distances. Transportation of limestone as slurry by pipeline for cement manufacture is nothing new. The first pipeline transporting limestone was commissioned in 1959. Since then, several pipelines have been in operation. Table 1 gives a list and the salient features of such pipelines.

3. The Assignment
CCIL wanted MECON to examine the feasibility of transportation of $2 \times 10^4$ t/a of limestone as slurry through pipeline for their proposed cement plant. Since the cement plant is proposed to be based on the semi-dry/cry process, transport charges should be worked out for delivery of both dried material as well as wet cake. The major design parameters for the study were as follows:

1. Throughput $2 \times 10^4$ t/a
2. Annual operating time 6,000 hours

Mr. S. R. Basu is Chief Design Engineer and Mr. A. K. Saxena is Senior Design Engineer, both with Metallurgical & Engineering Consultants (India) Ltd., Ranchi 834 002, India.
3. Feed material for cement manufacture
   a) Wet cake
   b) Dried limestone

4. Desired particle size for cement manufacture/transportation
   - 100 mesh, 85%
   - 170 mesh, 60%

Table 1: Limestone slurry pipelines in operation

<table>
<thead>
<tr>
<th>Company and Location</th>
<th>Pipeline capacity (10^4 t/a)</th>
<th>Length (km)</th>
<th>Pipe diameter (mm)</th>
<th>Year of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinidad Cement Ltd., from quarry to plant in Trinidad</td>
<td>0.45</td>
<td>10</td>
<td>200</td>
<td>1959</td>
</tr>
<tr>
<td>Rugby Portland Cement Co., from Kensworth Quarry to Rugby, U.K.</td>
<td>1.75</td>
<td>92</td>
<td>250</td>
<td>1964</td>
</tr>
<tr>
<td>Columbia Cement Co., from quarry to plant in Columbia, South America</td>
<td>0.35</td>
<td>16</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>Washington, USA</td>
<td>1.15</td>
<td>51</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Calaveras Cement, Div., of Flintkote Co., California, USA</td>
<td>2.0</td>
<td>27</td>
<td>175</td>
<td>1971</td>
</tr>
<tr>
<td>Gladstone, Australia</td>
<td>1.8</td>
<td>24</td>
<td>200</td>
<td>1981</td>
</tr>
</tbody>
</table>

4. Infrastructure Requirement

The overall scheme of transporting limestone as slurry is depicted in Fig. 1. Basically the scheme involves crushing/grinding of limestone to the desired size for transportation, mixing with water in the desired proportion and pumping the slurry along the pipeline. At the receiving terminal, the slurry is dewatered and/or dried for usage in the cement plant depending on the process for the production of cement.

The primary requirement for slurry transportation is the availability of water and power. The annual requirements for the present case are estimated as $1.65 \times 10^6$ m$^3$ and $36 \times 10^6$ kWh respectively. Fig. 2 shows the source of water, i.e., the rivulet, with the starting terminal location in the background. Besides water and power, housing is also to be provided for the personnel, as the proposed mine is located in a remote underdeveloped and thinly populated area.

5. System Design

To facilitate selection of parameters for transportation of solids as slurry, certain experiments are essential. The various investigations in bench scale and pilot plant scale were carried out at the laboratory of the Indian Institute of Technology, New Delhi, and are described below.
5.1 Investigations

5.1.1 Bench Scale and Rheological Tests

The rheological characteristics of solid-liquid mixtures are highly dependent on the properties of solids and those of the carrier liquid. Some important properties are:

- Particle size distribution
- Chemical composition of solids
- Particle shape
- Specific gravity of solids
- Angle of repose of slurry
- Slurry specific gravity at various concentrations
- Slurry viscosities at various concentrations
- Unhindered settling velocity of solid particles

The run of mine (ROM) samples of limestone were crushed to the desired size for investigation prior to testing in the laboratory. Fig. 3 shows the pilot plant set-up.

![Schematic diagram of loop test facilities](image)

Fig. 3: Schematic diagram of loop test facilities

The particle size distribution of the sample, as determined in the laboratory, is depicted in Fig. 4. The chemical composition of limestone is given in Table 2. The average sphericity of the particles was determined and it was found to be greater than 0.87. The specific gravity of the limestone as determined in the laboratory was 2.89. Angle of repose was found to be in the range of 2 to 3° for a 60% solids in the slurry. The specific gravity of slurry was determined for various concentrations and is shown in Fig. 5.

![Specific gravity with concentration](image)

Fig. 5: Specific gravity with concentration

Table 2: Chemical composition of limestone

<table>
<thead>
<tr>
<th>Item</th>
<th>Max.</th>
<th>Min.</th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>53</td>
<td>45</td>
<td>50.60</td>
</tr>
<tr>
<td>MgO</td>
<td>3.0</td>
<td>0.5</td>
<td>1.04</td>
</tr>
<tr>
<td>SiO₂</td>
<td>8.1</td>
<td>1.1</td>
<td>4.25</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.14</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>R₂O₅</td>
<td>2.0</td>
<td>0.45</td>
<td>1.31</td>
</tr>
<tr>
<td>LOI</td>
<td>43</td>
<td>40</td>
<td>41.50</td>
</tr>
</tbody>
</table>

The viscosity of the slurry was determined at various concentrations and the results are depicted in Fig. 6. The particles were observed to have static settled concentration in the range of 70% by weight.

5.1.2 Pilot Plant Tests

Pilot plant tests were conducted at four different solid concentrations in the range of 50—65% by weight in 55 mm and 105 mm dia. pipeline loops. The pressure drops at various concentrations and different flow velocities were measured both in 55 mm and 105 mm pipelines and these are plotted in Figs. 7 and 8. The curves tend to become linear at higher flow velocity and are curved for the lower range of flow velocity. This is due to the fact that at higher flow velocities the slurry behaves as a near-homogeneous fluid.
Fig. 6: Viscosity with concentration

Fig. 7: Headloss vs velocities as a function of concentration, 55 mm closed loop pipeline

Fig. 8: Headloss vs velocities as a function of concentration, 105 mm closed loop pipeline

repeated passage through the centrifugal pump. However, this phenomenon will not occur in the actual pipeline as the slurry will pass through the reciprocating pumps only twice, while covering the entire distance. The behaviour of the slurry was found to be according to a Bingham fluid with the following equation:

\[ \tau = \tau_y + \eta \gamma \]

\( \tau = \) shear stress, dynes/cm\(^2\)
\( \tau_y = \) yield stress, dynes/cm\(^2\)
\( \eta = \) coefficient of rigidity, poise
\( \gamma = \) shear rate, sec\(^{-1}\)

From the test results it was concluded that the homogeneous Bingham model could be used for predicting pressure flow rate data in pipelines of larger diameter, as long as the flow velocities are kept above the deposition velocities.

5.2 Design Parameters

Based upon the above tests, suitable co-relations were arrived at to predict the friction losses for the proposed pipeline and the following parameters were finally chosen for pipeline transportation:

- Annual throughput: \(2 \times 10^6\) t/a
- Annual operating time: 6,000 hours
- Pressure loss model: homogeneous Bingham plastic
- Particle size:
  - 100 mesh, 85%
  - 170 mesh, 60%
- Pipeline dia.: 200/250 mm
- Slurry consistency: 55% by weight
- Velocity of flow: 2.2 m/s
- Slurry pH: 10—11
- Wear rate: 0.14 mm/a
- Flow regime: turbulent

Based upon the above parameters, the design of the pipeline was carried out and the salient features of the proposed pipeline are given in Table 3.
Table 3: Salient features of proposed pipeline

1. Location
   - Starting terminal: Choli, Chamba District, Himachal Pradesh
   - Intermediate pump house: Gaiatlu, Chamba District, Himachal Pradesh
   - End terminal: Kandroo, Kangra District, Himachal Pradesh

2. Distance
   - Existing road link between mines & Kandroo: 200 km
   - Straightline distance between mines & Kandroo: 70 km
   - Pipeline route length between mines & Kandroo: 78 km

3. Pipeline
   - Throughput: 2 x 10⁶ t/a
   - Annual operating time: 6,000 h

4. Major Plant Facilities
   - Starting terminal: Secondary crushing & grinding plant, storage tank & pump house
   - Pipeline: 250 mm and 200 mm nominal diameter pipes and an intermediate pump house
   - End terminal: Storage tanks, dewatering and storage for 20 days
   - Process control: Computerised process control
   - Telecommunications: Captive UHF/VHF micro wave system for voice and data communication

5. Requirements of major services
   - Power: 36 x 10⁶ kWh/a
   - Water: 1.65 x 10⁶ m³/a

6. Manpower: 147

7. Implementation schedule: 3.5 years

Table 4: Technical data of major equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>No. of Units</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary impactor hammer crusher</td>
<td>1</td>
<td>Capacity 450 t/h&lt;br&gt;Feed size — 150 mm&lt;br&gt;Product size — 30 mm</td>
</tr>
<tr>
<td>Ball mills</td>
<td>4</td>
<td>Type of grinding wet&lt;br&gt;Capacity 120 t/h&lt;br&gt;Feed size mm — 30&lt;br&gt;Product size — 72 mesh</td>
</tr>
<tr>
<td>Cyclones</td>
<td>4</td>
<td>Set of cyclones to classify 130 m³/h of slurry, + 72 mesh size particles will be weed out</td>
</tr>
<tr>
<td>Agitated storage tanks</td>
<td>4</td>
<td>Structural tanks of 2,000 m³ capacity with agitators</td>
</tr>
<tr>
<td>Mainline triplex reciprocating piston-type pump, with pulsation damper</td>
<td>3</td>
<td>Capacity 195 m³/h&lt;br&gt;Head 750 m WC&lt;br&gt;Motor 650 kW</td>
</tr>
<tr>
<td>Mainline reciprocating triplex piston-type pumps with pulsation damper</td>
<td>3</td>
<td>Capacity 195 m³/h&lt;br&gt;Head 1,000 m WC&lt;br&gt;Motor 850 kW</td>
</tr>
<tr>
<td>Agitated storage tanks</td>
<td>4</td>
<td>Structural tanks of 5,500 m³ capacity with agitators</td>
</tr>
<tr>
<td>Marconalflow reclaimer</td>
<td>4</td>
<td>Reslurrying capacity 390 m³/h at 50 to 60% solids concentration by weight, with necessary high pressure pump, slurry pump, etc.</td>
</tr>
<tr>
<td>Vacuum filters</td>
<td>8</td>
<td>Capacity 65 m³/h</td>
</tr>
<tr>
<td>Driers</td>
<td>4</td>
<td>Capacity 115 t/h</td>
</tr>
</tbody>
</table>

Table 4 gives the salient features of the major equipment considered in the above study.

Various alternative alignments were considered prior to selection of the final one (Fig. 9). The total route length of the pipeline will be about 78 km. The route has been selected based upon the available toposheets (1:50,000 scale). Total number of trestles/suspension bridges required will be about 8. Based upon the techno-economic evaluation, a tunnel about 2 km long was also envisaged to cross the Nangail hill about midway along the pipeline route. The right of way for the pipeline, except where there are bridges/tunnels, will be about 20 m in width, including provision for service corridors also. The pipeline will pass through agricultural, forest and barren land. The overall route length will cover 40% agricultural land, 42% forest land and the remaining 18% barren land.

6. Cost Estimates

The study was conducted to find out the capital and operating costs of the proposed slurry pipeline system. The broad capital cost estimates for the proposed limestone slurry
transportation excluding infrastructure facilities are given in Table 5.

Table 5: Capital costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Million Rupees11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant proper including slurry preparation, pump houses and main pipeline</td>
<td>354</td>
</tr>
<tr>
<td>Storage and terminal facilities</td>
<td>133</td>
</tr>
<tr>
<td>Interest during construction</td>
<td>29</td>
</tr>
<tr>
<td>Total</td>
<td>516</td>
</tr>
</tbody>
</table>

11 10 Rupees = 1 US Dollar, approximately

The above capital costs include costs of equipment, spares, structures, civil engineering works and erection, insurance, taxes and duties, engineering, supervision etc. The estimated transportation costs for 2 x 10^6 t/a limestone transportation to the proposed cement plant at 100% capacity utilisation were worked out for both the wet cake and the dried material. The total transportation charges in Rupees per tonne for the wet cake (14—18% moisture) and the dry limestone powder (5% moisture) were estimated to be Rs. 3.7 per tonne and Rs. 5.0 per tonne respectively. For computation of the economics it has been assumed that 50% of the capital cost will be made available as equity and the balance from loans.

7. Conclusion

Transportation of solids in slurry form through pipeline is an established technology on which several commercial installations are currently operating in the world. Techno-economic studies show that pipeline transportation of limestone from Choli to Kandrori of Himachal Pradesh in India is a viable alternative by which industrialisation of this comparatively under-developed area could be realised.

Acknowledgements

We thank the management of M/s CCIL for allowing us to publish the above paper based upon the techno-economic study carried out for them.

We are also grateful to Prof. R.C. Malhotra and Prof. V. Seshadri of the Indian Institute of Technology, New Delhi, for the various investigations carried out in their laboratory and pilot plant for the above study.

Finally, we wish to thank the management of MECON for permission to publish this paper.

References


[3] “Laboratory tests for studying the feasibility of hydraulic transportation of limestone”, IIT, New Delhi, Study carried out for Metallurgical & Engineering Consultants (I) Ltd.

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